Summary of Progress *of the* GEOLOGICAL SURVEY OF GREAT BRITAIN *and the* Museum of Practical Geology for the Year 1931

PART II

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Department of Scientific and Industrial Research

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I.—THE PRINCIPLES OF PALAEOZOIC AND LATER TECTONIC STRUCTURE BETWEEN THE LONGMYND AND THE BERWYNS

By C. B. Wedd, B.A.

Text-figures 1-4.

THE region here viewed in its tectonic aspect furnishes a link[1] between the aberrant orientation of the Berwyn saddle and the north-eastward fold-trend of the Longmynd elevation as of Central and North Wales in general. Its folds develop north-westward, directly between the Longmynd and Berwyn masses, an increasing tendency to bend round from the prevalent north-eastward towards an eastward axial direction (Fig. 1), and in so doing to contract with intercalation.

Tectonic forces and resistances: their primary effects of two kinds.—The structural plan of North Wales and its borderland is intelligible as the product of deep-seated forces acting northward against increasing opposite resistance, but modified profoundly in their action by other resistances—those, primarily, of a pre-existent elevation of intensely compacted Archaean rocks on the west, where it extends north-eastward through Anglesey as the greatest Archaean elevation in Wales or England, though only the north-eastern part of a greater : and, secondarily, of an important but minor elevation of similar age and trend on the east in the Longmynd.[2] Movement so effected may be defined as displacement farther north in relation to the Anglesey massif which must have approximated most nearly to a fixed position, such northward displacement in relation to it being irrespective of any possible general movement of a larger including mass in any other direction.

The diagram, Fig. 2A, illustrates the simple mechanical principle of deep-seated forces acting approximately due northward continuously throughout a wide field, in their reaction to either of these resistant masses of north-eastward trend. The northward forces must be ' resolved ' each into two component forces, as its directional applications due to the resistance. The one component acts north-westward against opposite resistance, which, so long as it remains rigid, is equal to that component; the other along the diagonal of the parallelogram of which two adjacent sides are coincident with the lines and proportional to the magnitudes respectively of the northward force itself and of the resistance evoked by its north-westward component. It is essential to realize that these two components, each here necessarily less than the northward force, since that force meets the resistance at an obtuse

[1] See C. B. Wedd and B. Smith in 'The Country around Oswestry' (*Mem. Geol. Surv.*), 1929, pp. 16-17, 21-2.

[2] See C. B. Wedd and B. Smith in ' The Geology of Wrexham' (*Mem. Geol. Surv.*), Part I, 1927, p. 24 ; also in ' The Country around Oswestry ' (*Mem. Geol. Surv.*), 1929, p. 20.

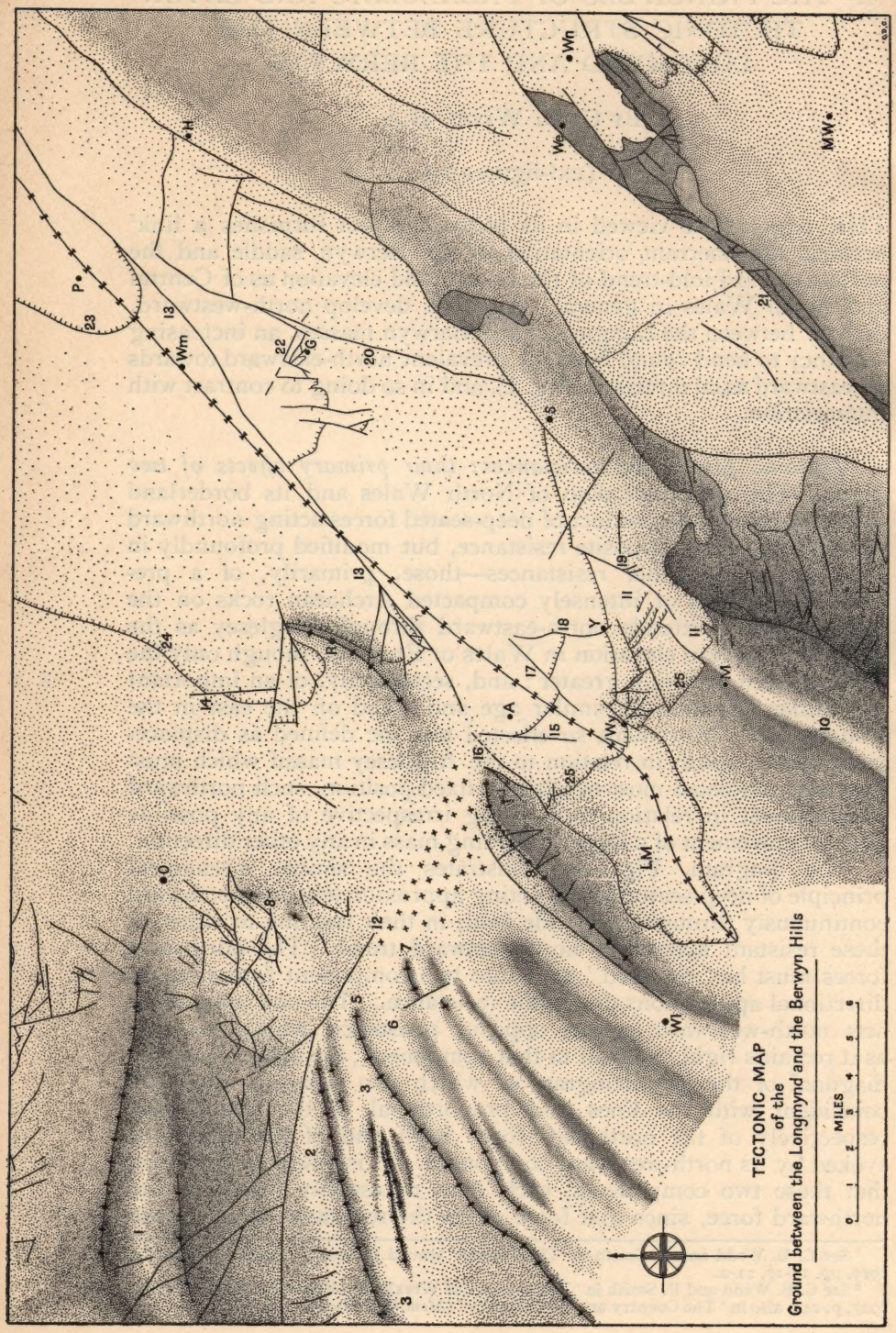


FIG. 1.—*Tectonic map of the district (for Explanation see opposite page).*

FIG. 1: *Tectonic Map of the Ground between the Longmynd and the Berwyn Hills: Explanation.*

A, Alberbury; G, Grinshill; H, Hodnet; L, Longmynd; L.M, Long Mountain; M, Minsterley; M.W., Much Wenlock; O, Oswestry; P, Prees; R, Ruyton Eleven Towns; S, Shrewsbury; We, Wrockwardine; Wl, Welshpool; Wm, Wem; Wn, Wellington; Wy, Westbury; Y, Yockleton.

Anticlines are shown by close stipple, densest where amplitude and steepness are greatest, and fading away towards the troughs of synclines: larger dots are used to indicate the broad top of the Breidden Anticline.

-◆-◆-◆-, anticlinal axes, where definite.

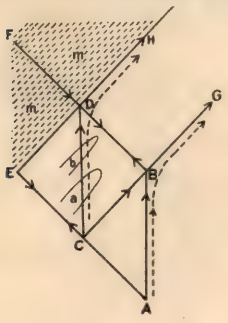
▼ ▼ ▼ / ▲ ▲ ▲, axis of Long Mountain Syncline: main axis of Shropshire and Cheshire Syncline.

× × × ×, structure unknown under drift and alluvium.

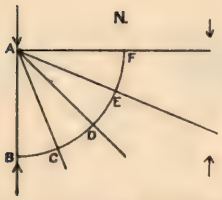
1, minor syncline between main crests of Berwyn Anticline.
2, sinuous northern trough
3, main southern trough (Llanfechain Syncline) } of compound Cain and Tanat Syncline.
4, main dividing anticline
5, Brogan Anticline.
6, Godor Syncline.
7, Pentre-heylin Anticline.
8, Sweeney and Llynclys Hill minor anticlines.
9, Breidden Anticline.
10, Venus Bank Syncline, between Shelve Hill Anticline on west and Stiperstones-Longmynd upfold on east.
11, Syncline of Pontesbury coal-basin.
12, Tanat Valley Fault.
13, Axial Fault.
14, Haughton Fault.
15, Pecknall Brook Fault.
16, Bryn-poeth, Braggington Coppice, and Lower Braggington Faults, in order from west to east.
17, Rowton Fault.
18, Cardeston Fault.
19, Rea Fault.
20, Brockhurst Fault.
21, Church Stretton Fault.
22, Basic dyke.
23, base of Lias.
24, ,, ,, Ruyton or Grinshill Sandstone (Keuper).
25, ,, ,, Upper Coal Measures.

Toothed lines denote outcrops where illustrative of structure, the teeth being in the general direction of dip.

angle, are different in effect. By its north-westward component acting against opposite resistance, the northward force effects compression, and consequently folding with axes at right angles to that component, through displacement only in its own northward direction, convergent with the trend of the resistant mass. Subsequently, as compression approaches its maximum, e.g., at B, the north-eastward diagonal component (' resultant force ') comes into action and induces diversion of movement more and more towards



A



B

Explanation of Fig. 2A.

m, m, resistant mass.

AB, CD, forces acting northward.

FD, DB, resistance at points D and B.

BD, DF, components of AB, CD, acting in direction of compression against equal resistance.

CB or BG and ED or DH, components (' resolutes ') of AB and CD respectively in ' resultant ' direction of movement.

a, b, successive positions of a fold in approaching m, m.

----→ direction of movement, resulting in faults along DH, BG.

For explanation of Fig. 2B see p. 11.

FIG. 2.—*Diagrams to illustrate formation and movement of parallel folds and faults* (A), *and the principle of the crescentic Ruyton Anticline in its relation to the Berwyn Anticline* (B).

that direction upon increase of south-eastward resistance with increasing compression. If, however, that resistance was initially rigid, e.g., at D, north-eastward diversion would there take place initially. Thus, wherever south-eastward resistance is adequate, the north-eastward resultant force may produce a tear or fault in its own direction, parallel to that of fold trend, and with horizontal displacement in that direction along its south-east side. The direction of the north-westward ' resolute ' of such northward force may conveniently be termed the ' direction of compression,' that of the other ' resolute ' the ' resultant direction of movement.'

In the solid crust of the earth there must, of course, be resistance to all movement in any direction. Here of other resistances the most effective, as evoked by the greatest force, must have been a cumulative southward resistance to the direct action of the northward drive. For all resistance must increase to its maximum with increase of the force that evokes it.

Of three great folds, comprising two anticlines separated by a syncline, successively compacted against the resistance of the Anglesey Archaean massif as a barrier and all containing complications not relevant to the present purpose, the nearest to the region here under consideration is the great Harlech Anticline. South-east of this the Berwyn Anticline, swerving abruptly eastward, with great increase of magnitude, from its previous north-eastward course,[1] introduces an anomaly as a consequence of certain modifying influences farther north and a cause of modification in this district.

Of the parallel faults of north-eastward trend and lateral displacement inferred as a natural product of the simple tectonic principle, two of great functional importance are the Dinorwic along the Menai Strait and the Bala Fault along the south-eastern flank of the Harlech Anticline, as well as the Church Stretton Fault outside the scope of this account. To these must here be added another to be discussed later as the ' Severn Fault ' along the Severn valley by Welshpool. These and other tectonic features represented in Fig. 1 for the most part will not be described in detail here.

Most of the folding movement in North Wales, with the initiation of such faults, took place between early Devonian and a late stage of Lower Carboniferous time[2]; but here no inconsiderable part of it preceded the deposition of Silurian sediments.

The Longmynd rampart: its behaviour and influence.—The Archaean rampart of the Longmynd with its north-eastward continuation in Haughmond Hill, and with the Wrockwardine and Wrekin tracts also as original constituents of its mass, acted as a buffer, which, even when giving way or crumpling before the northward drive, always afforded protection in varying degree to the less resistant masses both north and north-west of it.[3] It minimized displacement northward and consequent deformation north of itself, while also staving off from the strata on its north-west side a considerable access of north-westward pressure.

Its deformation and elevation must have been great even before Cambrian times; for the basal Cambrian strata, themselves highly inclined, were laid down in the Wrekin across the denuded edges of Uriconian rocks then nearly vertical. Undoubtedly of anticlinal origin, however much disguised by overfolding with faulting, and itself continued north-eastward by a long line of anticlinal flexure in the later rocks, it early determined the position of the great Shropshire and Cheshire Syncline, next beyond and complementary to its own upfold, in accordance with the regional trend of folding imposed by the ' direction of compression ' (p. 4) against the ultimate resistance of the Anglesey barrier.

[1] Wedd, C. B., and B. Smith in ' The Country around Oswestry ' (*Mem. Geol. Surv.*), 1929, p. 15.
[2] Wrexham Memoir, Part I, 1927, p. 17.
[3] Oswestry Memoir, 1929, p. 20.

The strongest evidence that it offered great resistance to the northward drive is found in the marked tectonic contrast between the ground directly north of it and that farther west. For west of its meridian the eastward axial orientation of violent folding under exceptional conditions, there resulting in the diverted Berwyn Anticline and the Llangollen Syncline (Sheet 121), as a variant from a generally intense multiple folding of north-eastward trend, gives place eastward rather suddenly to a broad synclinal basin (Fig. 1) filled with Carboniferous and later sediments gently flexed upon that axial trend.

Further evidence of such resistance is furnished by the great lateral movement past the main mass of the Longmynd elevation along the Church Stretton Fault on its south-east side.

The north-eastward elongation of the Archaean ridge would give it greater strength as a rampart or buffer to resist forces acting northward directly upon it than if the direct application of equivalent forces had been north-westward. In yielding to northward displacement, it would be buckled back from the south. The Longmynd mass, as the southern part of the whole original elevation inclusive of Haughmond Hill and Wrockwardine, would be driven back upon the next part to the north, without the latter suffering displacement to the same extent; and the same process may have been continued farther at successive periods, the Longmynd itself moving northward together with the tract west of it. Thus, on giving way from the south northward, the whole Archaean mass would renew its resistance after successive displacements, as a protecting rampart to the ground north and north-west of it against still further northward displacement and consequent north-westward compression. Its periodic but diminishing displacement would be consistent with long intervals of more or less rigid resistance.

Moreover, north-westward pressure of the northward forces on its south-east flank would check a north-eastward tendency imparted by the resultant direction of movement (p. 4) on the west side.

That the Longmynd rampart did give way periodically is proved by the folding immediately north-west and north of it. Displacement occurred before the beginning of Silurian time, with consequent flexing of deposits north-west of it and subsequent overstep by the Silurian on to it (Fig. 4), and in less degree on to the opposite Breidden Anticline (Fig. 1), after denudation: again during the Devonian movements, when renewed folding on the same lines strongly flexed the Lower Palaeozoic rocks in the Cheshire and Shropshire Syncline, with elevation at its south-west end and subsequent denudation more complete on the south-east limb of the fold than in the trough, where Upper Coal Measures were ultimately banked against the Ludlow and Downtonian eminence of the Long Mountain: and again with less effect at apparently more than one stage since Carboniferous time, even

after the deposition of the Middle Lias, of which an outlier is infolded in the trough of the syncline at Prees (Fig. 1).

The even nature of folding at its several stages in the trough of this great syncline, with the rarity of minor plication as well as the absence of cleavage from the Silurian strata of the Long Mountain (of which the north-eastern part lies due north of the terminating Longmynd) contrasts with the more severe and complex folding farther west and must be ascribed to the restraint still exercised by the Longmynd rampart, whenever it gave way.

Unless the whole balance of forces acted in the opposite direction to that postulated, so that the much greater Anglesey massif moved southward, while the lesser barrier of the Longmynd remained comparatively rigid, the Long Mountain Syncline could not have come into existence without displacement of the Longmynd ridge. And this applies equally to successive folds north-west of it, until their trend changing gradually from a north-eastward to an eastward direction assigns the farther of them, in the vicinity of the Berwyn Anticline, to the influence of northward pressure against southward resistance.

The direct application of primary forces acting north-westward against opposite resistance could equally by displacement in that direction have given rise to the system of parallel folds trending north-east. But only the north-westward pressure-application of forces acting northward could produce that effect against the same resistance without excluding other concomitant phenomena. Moreover, a northward buckling of the original Longmynd ridge would increase and stabilize its resistance only to forces acting northward or north-eastward.

In the north-westward direction of compression against the Anglesey barrier by primary forces acting northward, pressure would increase with decreasing distance from that barrier, and would be greatest against the south-western part of it, outside any protective interference by the Longmynd rampart. There parallel lines of anticlinal upfold would first develop, with fold-intensity diminishing north-eastward. Between that tract of prevalent elevation and the Longmynd Anticline the synclinal area complementary to both would remain as a comparatively simple fold, unless increased north-westward squeeze resulting from further northward displacement of the Longmynd necessitated further plication, with consequent encroachment of new folds mainly upon the north-western and wider limb of that syncline. It was primarily the resistance of the Longmynd rampart, and secondarily also a protective horizontal arch of folds (p. 8) compacted by its partial yielding, that saved the great synclinal basin from further encroachment. Actually that syncline is interrupted only by the Ruyton Anticline (p. 10), a by-product of other external conditions.

Torsion and the eastward diversion of the Berwyn Anticline.— Thus by inducing a north-eastward diminution of pressure against

the Anglesey barrier and so increasing the effect of resistance on the north in relation to a diminishing north-eastward resultant of movement (p. 4), the Longmynd rampart facilitated a tendency to spiral torsion[1] in the clockwise direction within the area of partial protection north-west of it—a tendency carried out by powerful movement along the Dinorwic Fault and subsequently along the Bala Fault.[2]

The generation in this way of a southward counter-force in opposition to, but at a higher level than, the deep-seated northward force compelled the Berwyn Anticline to develop with an abrupt bend round from north-east to east between opposing forces, with much increase of fold-amplitude, and with some degree of southward overfolding—a diversion that greatly influenced this adjacent district.

The curved pressure-belt as a protective horizontal arch.—The northward displacement permitted by the yielding of the Longmynd ridge, while evidently considerable in the south, was presumably small in relation to the great expanse of the synclinal basin north of that ridge. But this displacement gave rise, by consequent north-westward pressure, to a belt of compression that curved north-westward from the Longmynd round to northward against the Berwyn Anticline, with increasing multiplicity of transverse folding (see Fig. 1). For compression would increase progressively north-westward (and consequently nearer to maximum resistance) with gradual change from that to a northerly direction of pressure under the increasing influence of northward forces applied farther west more and more directly against the opposing Berwyn mass. The belt of pressure so produced, with the radial tendency of its compacted transverse folds, would have the effect of a horizontal arch, convex to the south-west, in binding together the Longmynd and Berwyn anticlines so as to strengthen resistance to external pressure and thus to afford further protection to the great synclinal basin within. Hence the contrast between the complexity of folding into which the north-western limb of that great syncline passes south-westward by interdigitation with anticlines in the Lower Palaeozoic rocks of this pressure-belt and its simplicity in later formations farther north-east, as presumably also in the underlying older strata. For those anticlines, individually ample and steep folds where they cross that belt, do not perceptibly affect the Carboniferous and Triassic strata within the synclinal basin, and there is no evident reason for their continuation, which by their convergence towards the main synclinal axis would lead to mutual interference. The south-west end of the narrower south-eastern limb, more remote from extreme resistance and subjected to simple north-westward

[1] Wedd, C. B., in 'The Geology of Flint, Hawarden, and Caergwrle' (*Mem. Geol. Surv.*) 1924, p. 16; C. B. Wedd and B. Smith in 'The Geology of Wrexham' (*Mem. Geol. Surv.*) Part I, 1927, p. 24.

[2] Oswestry Memoir, 1929, p. 20.

pressure, appears to be uniform in the Lower Palaeozoic rocks except where it rises towards the Longmynd elevation (Fig. 4).

The curved pressure-belt is marked by a series of transverse anticlinal outcrops of Ordovician strata between a continuous expanse of folded Silurian rocks on the south-west and an unbroken outcrop of unconformable Carboniferous, mainly Upper Coal Measures, on the north-east. The increasing pressure along this belt effected a general upward squeeze in folding, upward even in the only notable synclinal interruption of Ordovician outcrop by the Silurian tract of the Long Mountain, where denudation at its north-east end proves great actual elevation of the synclinal trough before the deposition of those Coal Measures. As a consequence of this upward squeeze a zigzag line meandering along the belt of pressure separates a region of south-westward fold-pitch on the south-west from one of north-eastward fold-pitch on the other side. Hence the change of pitch, noted elsewhere,[1] between the Cain and Tanat Syncline[2] in the Lower Palaeozoic rocks and the shallow synclinal basin south of Oswestry in the Carboniferous rocks, beneath which the Lower Palaeozoic strata presumably have the same north-eastward fold-pitch. Where both compression and northward bend in this pressure-belt reached their maximum towards its north-west end, there the folds are more closely packed and thence they diverge in trend between westward and south-westward:[3] e.g., the Llanfechain Syncline and the Brogan Anticline (Fig. 1) run parallel with a distance of barely a third of a mile between their axes where they cross the belt westward to the vicinity of Llanfechain, beyond which the Brogan Anticline diverges rather widely south-westward.[4]

All such anticlines, where mapped, have a steepened or even locally inverted southern or south-eastern limb[5] in consequence of a tendency to underpush north-westward and northward or to overpush in the opposite direction, by reason of the difference of level at which force and counter-force acted in relation to one another and to resistant masses.[6]

North-and-south tension faults in the Shropshire and Cheshire Syncline.—Compression along the curved pressure-belt has another effect upon the main syncline farther to the north-east. Faults of northward trend, all apparently of short range, are disposed irregularly around the outcrop-curve of the Shropshire and Cheshire Syncline in its southern half, five out of seven having downthrows in accord with the tendency of folding, eastward on the north-west and westward on the other side of the synclinal axis. North-westward pressure resulting from northward displacement

[1] Oswestry Memoir, 1929, p. 18.
[2] *Op. cit.*, p. 16.
[3] *Op. cit.*, p. 16.
[4] *Loc. cit.*
[5] King, W. B. R., quoted in *op. cit.*, p. 17. The axes of folding between the Berwyns and the Vyrnwy valley, as represented in Fig. 1, were traced by Professor King, to whom acknowledgment is due.
[6] See C. B. Wedd and B. Smith in *op. cit.*, p. 22.

was greater in the south-western part of the synclinal basin than farther north-east, since not only is the width of the basin in the middle of its course greater on any measurement than the distance at its south-west end between the Longmynd and the Breidden Anticline, but also the strong plication of its north-western limb at that end must be assumed to cease north-eastward in the Lower Palaeozoic formations outside the field of the exceptional pressure that produced it. Consequently the difference of north-westward pressure across distant parts of the fold would set up east-and-west tension diagonal to the parallel lines of unequal pressure in those parts, and faults would develop at right angles to the tension. Such tension-faults would normally let down the strata on the side dictated by the tendency of folding. Moreover, since their direction diagonal to pressure shows that no single fault of this kind could divide the basin into two areas of high and low pressure, such faults must have a comparatively short range and would be stepped at intervals around the basin, i.e., along its septal tracts of greatest flexure.

The Ruyton Anticline as a product of torsion.—It had been anticipated that on that side towards which the terminating Berwyn Anticline is overpushed and at some undefined distance south-east of it, there must exist at least one subsidiary anticline with outwardly convex axial curve tending to develop across the axial direction of that greater fold.[1] Such an anticline passes through Ruyton Eleven Towns (Fig. 1) with curve from a north-eastward to a northward axial direction and with northward pitch. Its recognition for about three miles of its trend through Ruyton is due to its there bringing to the surface the resistant Keuper Sandstone. Drift conceals its further course northward; while its south-westward continuation, with bend nearer to a westward trend, is suggested by scanty exposures in the Bunter only to a short distance beyond Kinton (Sheet 137). But its position, trend-curve, and northward pitch or diminution sufficiently indicate its tectonic relationship to the termination of the Berwyn Anticline.

The great contraction of area implicit in the severe folding of the Berwyn Anticline must have some counterpart in, or some adjustment to, the region not so affected beyond its rather sudden eastward termination. The Ruyton Anticline, with its complementary syncline, is one, but not necessarily the only, instrument of such adjustment. As a natural accompaniment of the terminating Berwyn Anticline and a further product of torsion, it depends in principle on two mechanical ' couples ' of forces, deducible from the inferred conditions.

The northward underpush or southward overpush of the diverted Berwyn Anticline, in a net northward displacement,

[1] For other illustrations of the principle of transversely curving and terminally embracing subsidiary anticlines, see C. B. Wedd in ' The Geology of Flint, Hawarden and Caergwrle ' (*Mem. Geol. Surv.*), 1924, p. 10; also in ' The Geology of the Northern Part of the Derbyshire Coalfield ' (*Mem. Geol. Surv.*), 1913, pp. 8-10 and Fig. 2.

implies a ' couple ' of opposite forces acting horizontally in a vertical plane. In this ' couple ' the southward counterforce developed by torsion and reinforcing the resistance to a deep-seated northward drive must function at the higher level as a dominant force of relatively southward displacement. At this higher level farther east, beyond the field of this torsion, a further decreased northward force would represent the deeper-seated force of that direction, itself diminished, but probably not nullified, by the resistance of the Longmynd mass. The Berwyn Anticline would thus die down eastward: and in the counter-clockwise torsion set up by this ' couple ' in the horizontal plane, a system of radial pressures would develop within the continuous medium affected, with successive diminution of force on divergence from a southward towards an eastward direction of pressure. The principle is illustrated by Fig. 2B, in which any incipient movement of the point A towards B implies immediate shortening of the distances AB, AC, AD, AE in degree diminishing successively from AB to AE, but lengthening instead of shortening of the distance AF. Thus in a compressible solid medium compression on the left side by force acting along AB will have produced a system of pressure-lines radiating from A in its new position, the pressures along them diminishing successively from AB to AE (if the displacement of A towards B be not excessive), while along AF there will be tension instead of pressure. For such a displacement of A the wrinkle produced across AB would diminish along its axial curve across AC, AD, AE, and would not reach AF, there being in this illustration no displacement on the right side by pressure of opposite direction to that on the left.

In the application of this figure to the Ruyton Anticline the shortening of the distance AB, which necessitated shortening of other radial lines, was itself probably all accomplished by the north-and-south contraction in the Berwyn folding. In that case the Ruyton Anticline would die out westward and would have its maximum amplitude at some position between its intersections with the lines AC and AE.

Excessive displacement of A towards B on the left side or appreciable opposite displacement on the right side in the action of the ' couple ' of forces would each cause variation in detail, while the principle would remain the same.

Faint anticlinal folding of similar north-eastward trend in the Carboniferous Limestone of Llynclys Hill[1] (Fig. 1), with an uncertain continuation farther north, may be a second and inner crescentic fold of similar function.

The Ruyton Anticline is accompanied on each side by synclines of like trend and pitch. Of these, that on the south-east is the axial trough of the Shropshire and Cheshire Syncline, while the other represents merely the outer part of the limb of that greater

[1] Oswestry Memoir, 1929, p. 17.

syncline as flexed into a separate fold and accentuated by the intrusion of the anticline.

The completion of such torsion-movements in this region belongs to a relatively late stage, subsequent to the deposition of the Trias.

Radial faulting in the syncline.—The Ruyton Anticline by intruding into the great syncline overstrained the bending strata and so gave rise to two groups of radial faulting, one on each side of itself, but both radiating outward from the original syncline and across the directions of increased tension on the two synclinal curves so accentuated (Fig. 1). The group between the anticline and the main synclinal axis shortened the line of curve by an imbricate packing, with southward downthrows towards the synclinal trough, under continued north-westward pressure; which also, combined with movement along the Axial Fault, bent up the south-eastern edge of the tract so affected and thus for some distance completed a synclinal structure on the north-west side of that fault.

In the other limb of the great syncline, with its strong curve of outcrop presumably exaggerated by the same fault-movement, a similar fault-group radiates outward in the neighbourhood of Grinshill (Fig. 1) and seems to include a fracture injected later with dolerite. In this case, however, it apparently took advantage of pre-existent north-and-south tension-faults, as is suggested by south-eastward divergence on the east side of those parallel faults and by the like divergence of a single fault from the most western of them. It may even have induced a fault-trough by further tension between two of them and so explain an eastward downthrow unusual for any such fault in this limb of the syncline. In any case it supports the inference to be drawn from the displacement of the Haughton (Fig. 1) by a radial fault west of the Ruyton Anticline as to the priority of the north-and-south faults sprung from differential pressure in that movement which resulted in torsion, equally to these radial faults and to that anticline as consequences of torsion. All three phenomena were post-Triassic in their completion, but not all necessarily in their inception.

The Severn Fault and the resistance of the Berwyn mass.—But the torsion that resulted in the eastward diversion of the Berwyn Anticline exercised a further disturbing influence upon this district. The northward forces acting upon that elevation both directly, and also farther east indirectly, would meet two main forces of resistance: (1) south-eastward resistance due primarily to the Anglesey barrier; (2) southward resistance and counterforce inherent in and transmitted through the Berwyn mass, these latter changing their direction and progressively diminishing in effectiveness eastward beyond its termination in their opposition to the northward forces applied farther east. In their action as a northward drive, with consequent pressure north-westward,

against the two main forces of southward and south-eastward resistance, the northward forces would develop every intermediate direction of pressure and would evoke resistance in every opposite direction; for they would be acting, not upon separate and independent bodies, but in one continuous solid medium. In the further compacting of that medium, and the incidental production of folds across the curved pressure-belt already discussed, the resistances of that south-eastward and southward group would all increase in effectiveness at successively greater distances in their own several directions, until eventually lines of south-eastward, southward, and intermediate resistant force would all meet in opposition to the active forces of northward drive and north-westward pressure with their intermediate directions of application. There stresses would be greatest, and the whole system would have one common resultant in some direction between north-east and east. There ultimately, unless the stresses were relieved in some other way, such as the break-down of resistance, a fault would develop in that resultant and also in the opposite direction, to allow movement in the resultant direction along its south-east side. Its opposite direction of development, on passing more and more under the influence of south-eastward resistance to northward force, would approximate to the line of the north-eastward resultant of those forces. Thus the fault so produced would trend north-east for some undefined distance and would then swerve in some degree eastward of that direction, so as to point east of the resistant Berwyn mass on the north. For the greater the eastward prolongation of that mass, the wider would be the field of southward resistance and the greater the eastward deflexion of the resultant. Differential displacement north-eastward along the south-east side of the fault would increase proportionately to compression on the other side as the northward drive continued; and it would tend to decrease again on deviation towards an eastward direction. In other words, compacting of the strata under stress of such continuing force and resistances would result in a rent and a swerve of movement in the direction of least resistance, to avoid an obstruction.

Just where such a fault might be expected (though there may be more than one), the Severn valley, in its north-eastward course below Welshpool, passes close under the high cliff-like brow of the Breidden dolerite. There the truncation of the north-western limb of the Breidden Anticline with its massive dolerite intrusion and the wide displacement of formation outcrops indicate a fault[1] of the required lateral movement. Moreover, the curve of the pressure-belt as drawn from the Longmynd through this anticline at its greatest amplitude suggests dislocation of the horizontal arch of compression in the same direction by that fault; for a continua-

[1] No fault is shown on the Old Series map (60 N.E.) of the Geological Survey. But Prof. W. W. Watts states: 'It is practically certain that the Severn valley here is a faulted trough (see Fig. 38, p. 357) which has broken off the lower part of the rock sequence': see 'The Geology of South Shropshire,' *Proc. Geol. Assoc.*, vol. xxxvi, 1925, p. 343.

tion of the curve so drawn would almost miss the Berwyn elevation. However great the resistance of that horizontal arch to even pressure from the south and south-west, it would not be equally resistant to the differential pressure set up by the development of this Severn Fault in a radial direction. But such disruption would not necessarily destroy its resistance to uniform pressure.

The Severn Fault, in swerving past the east end of the Berwyn Anticline, could not continue far in any deflexion eastward of the north-east resultant direction. For, if continuing far, it seemingly must revert to that north-eastward direction on passing beyond the influence of the Berwyn resistance. It would then resume the resultant direction between northward force, there transmitted by yielding of the Longmynd rampart, and the general south-eastward resistance. It would run with or parallel to the fold-axis of the great syncline as determined by north-westward pressure against opposite resistance, if that resistance were uniform. Actually, however, the resistance could not have been uniform, where the system of parallel folding along axes of north-eastward trend had given place on the north-west to the disturbing effects of torsion.

The Axial Fault and its relation to the Severn Fault.—There is no proof that the Severn Fault does so continue. But either that fault does, or another, the Axial Fault,[1] of similar displacement, carries on the same north-eastward movement along an adjacent line a little farther east. For the Axial Fault, slightly oblique to the synclinal axis and passing to its south-east side, effects along that side of itself a north-eastward displacement of the synclinal Triassic outcrops comparable with that of the Lower Palaeozoic outcrops by the Severn Fault, though no doubt exaggerated in the denudation of slightly inclined strata.

If the Severn and Axial faults are one continuous fracture, they are so by virtue of a double swerve, from north-east towards east and back to north-east, just where such a swerve ought to be expected for more than one reason connected with the position and resistance of the Berwyn Anticline. For in addition to the direct effect of that resistance, as discussed above, upon the resultant between the general regional south-eastward resistance and a northward drive, any further degree of northward movement since the initiation of the Severn Fault would displace it bodily and so increase its eastward swerve by bending. The Ruyton Anticline, too, as a subsidiary product of the Berwyn torsion, would have a similar effect upon a connecting link between the Axial and Severn faults during or after their development, in its function of adjustment between a more and a less contracted region; for by its own contraction it would induce a further and similar distortion of a fault-line tangential to the convexity of its axial curve. Again, any later prolongation of the Tanat Valley faulting south-eastward (where its extent is unknown) under stress of northward drive would

[1] Pocock, R. W., and D. A. Wray in 'The Geology of Wem' (*Mem. Geol. Surv.*), 1925, p. 56 and Pl. II.

result in an increase of *net* eastward displacement on its north side, and so would farther separate the lines of the Axial and Severn faults by dislocation.

The Severn Fault, unlike the Bala and Dinorwic faults, must have been later in its initiation than the eastward diversion of the Berwyn Anticline at an early stage of the torsional movements, but seemingly not later than the last important phenomena of torsion, such as the Ruyton Anticline. The Axial Fault, doubtless initiated not long after the Severn Fault, is known only as affecting the Mesozoic sequence up to the Middle Lias; while the Ruyton Anticline, evidently later than the north-and-south faults (p. 12), presumably also did not reach its full development until after Middle Liassic time.

Internal adjustments due to diversion along the Severn Fault.—A north-eastward swerve of movement effected through the agency of the Severn Fault could not be a simple rotation north-eastward, but could only be carried out piecemeal through faulted internal adjustments by which some parts were squeezed forward beyond others. For it would come into opposition to the north-westward pressure of the northward drive transmitted farther east by the yielding of the Longmynd rampart.

On relief of stresses by the Severn Fault, but before the development of the Axial Fault, a spiral tendency would be imparted to the increasing eastward swerve from the north-eastward resultant direction of movement by cumulative resistance on the north. By reason of that relief and of its own peripheral position, the belt of ground along the south-east side of the Severn Fault would at first move more freely, and at a greater rate than the rest of the tract affected. But the Axial Fault, as it developed, would destroy such spiral tendency in that tract by restoring the north-eastward resultant of movement. The eastward swerve of the Severn Fault, or, if that fault did not continue and swerve far enough to join the developing Axial Fault, then resistance on the north in the intermediate ground in which the stresses were not relieved, would check the advance of that outer belt, when the direction of movement became again north-eastward. The outer strip so held up would be torn off and left behind on the initiation of the Bryn-poeth Fault (Figs. 1 and 3), and north-eastward displacement would continue along the south-east side of the new fault, where in turn it would be greater than in the rest of the tract affected.

The forward thrust of the outer strip between the Severn and Bryn-poeth faults, when checked by resistance on the north before isolation by the latter fault from the rest of the moving mass must have bent the Breidden Anticline round eastward against that resistance. One effect of this is seen in the group of divergent and convergent faults that displace the escarpment of the massive ash along the crest of Bausley Hill in the steep southern limb of that anticline. These have a radial tendency due to the axial

bend, but obscured and partly counteracted by the packing of overlapping segments in an irregular imbrication, through an effort to shorten the outcrop under resistance to its north-eastward movement.

With increasing distance eastward (and incidentally from the curved pressure-belt) resistances on the north-west would have less effect owing to relief of stresses by the Severn and Bryn-poeth faults, and the resultant direction of movement would change more towards the northward direction of the primary forces (cp. the Brockhurst Fault, Fig. 1). Consequently there would be

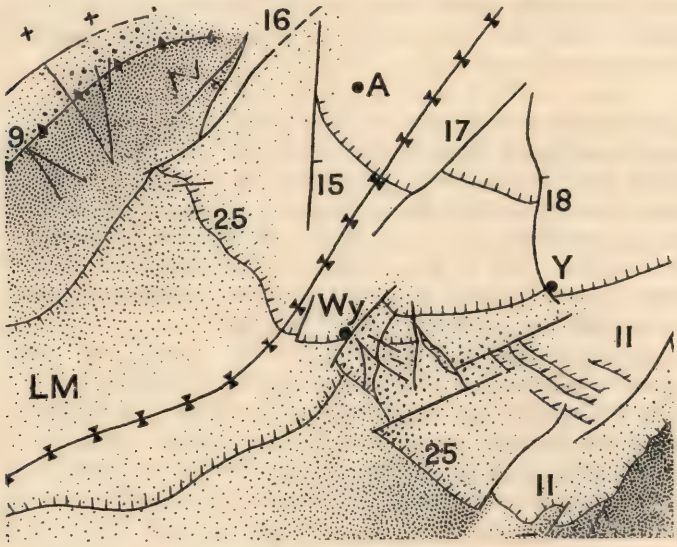


FIG. 3.—*Enlarged tectonic map of Alberbury, Westbury and Pontesbury tract. Explanation as for Fig.* 1, *p.* 3.

renewal of squeeze on the west side with each successive displacement. No economy of space would follow the development of the Lower Braggington Fault by itself in the prevalent north-eastward resultant direction, parallel to the Bryn-poeth and Severn faults. But if at the same time the Braggington Coppice Fault[1] of north-north-eastward trend came into existence between the Lower Braggington and Bryn-poeth faults so as diagonally to split the tract being squeezed forward between those parallel faults, then the wedge pointing south on the east side of the diagonal fault would slide forward under compression past the western wedge pointing north (Figs. 1 and 3). Thus some further forward movement would become possible with transverse diminution of space. But the strip confined between the two parallel faults and terminating north-eastward in the western wedge would be checked in its forward movement and would suffer some internal distortion either during or after the development of the diagonal

[1] This and the two parallel faults are not shown on the old map of the Geological Survey. The Braggington Coppice Fault had long been known to Prof. Watts as throwing down red Coal Measures against red-stained Bala shales in the Braggington brook.

fault. Actually its north-eastern part seems to have been screwed round clockwise, so that in it the regional north-eastward strike, already diverted eastward in the east end of the Breidden range within the dislocated (p. 13) arch of the pressure-belt, was further diverted south-eastward with south-westward dip, as is shown by a small escarpment of Caradocian limestone between the Bryn-poeth and Braggington Coppice faults (Fig. 3).

The Bryn-poeth Fault, which has a similar lateral displacement to that of the Axial Fault, but with an effect of opposite south-eastward downthrow due to reversal of dip, is likely to have been initiated independently of that fault, which it may ultimately meet, as may also the Severn Fault.

As here interpreted, the Braggington Coppice Fault could not effect any great displacement either horizontal or vertical: it assumes an exaggerated importance on the map as marking the boundary between the Upper Coal Measures and the Caradocian. While red Ruabon Marl at the base of those Coal Measures rests upon stained Bala Shales in the Braggington brook on the east side of the fault, traces of staining persist in those older beds so far westward as to suggest the former presence of overlying Ruabon Marl also on the west side of the fault.

The Brockhurst and Hodnet Faults.—However far the outcrop of the Keuper Sandstone was displaced northward by horizontal movement along the Axial Fault, it was displaced a somewhat greater distance eastward. But the forces of northward drive farther east, by their north-westward pressure upon the anticlinal continuation of the Longmynd elevation, undoubtedly minimized or prevented eastward displacement on that side. So the north-eastward resultant force acting along the south-east side of the Axial Fault would make with the northward force acting farther east through the yielding Longmynd mass a further resultant in some intermediate direction, and this further resultant would be a greater force than either of them, since they converge at an acute angle. Thus the tract between the Brockhurst and Hodnet faults[1] (Fig. 1), which at first diverge and then develop parallel in this resultant direction, may have been squeezed and pushed forward in this direction, the squeeze inducing some attempt at subordinate folding between internal parallel faults, the push probably a packing at cross faults westward of Hodnet. But such forward movement is not to be measured by the great distance between the outcrops of Keuper Sandstone on opposite sides of the Brockhurst Fault: for the fault-trend there approximates to the strike of the strata along the septal tract of folding. Whatever the amount of direct lateral movement along its east side, there must have been corresponding displacement along the west side of the Hodnet Fault, where, however, the map affords no evidence for or against such movement in either direction.

[1] Pocock, R. W., in 'The Geology of Wem' (*Mem. Geol. Surv.*), 1925, pp. 58, 59.

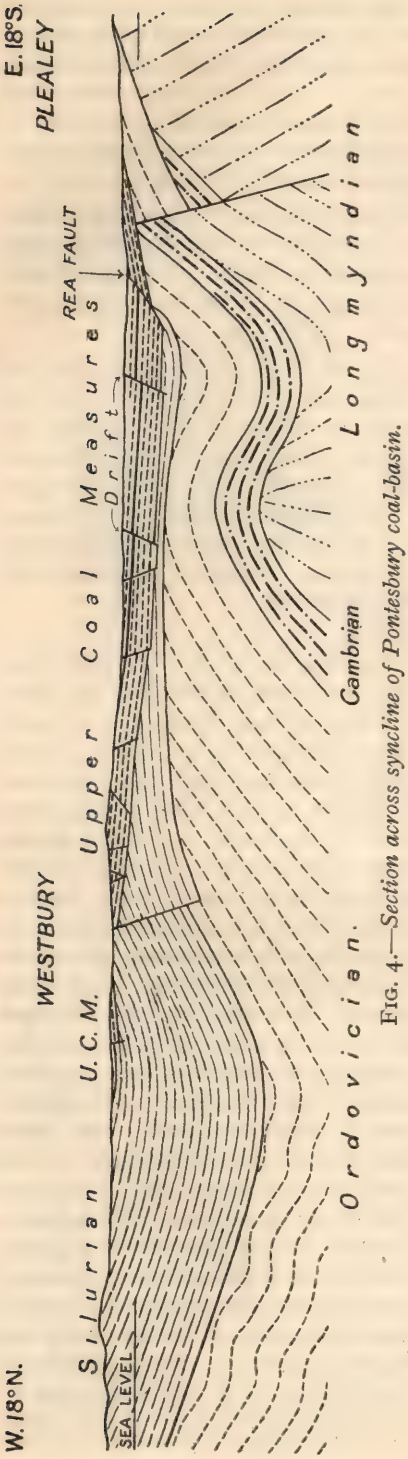


FIG. 4.—*Section across syncline of Pontesbury coal-basin.*

It should of course be recognized that the forces responsible for such tectonic effects acted at unknown depths below such 'incompetent' masses as the Carboniferous and Triassic strata, which conformed to or varied the later movements, especially of faulting, imparted to more compacted masses below without becoming similarly compacted.

The superficial syncline of the Pontesbury coal-basin.—The even regularity of periodically increased synclinal folding under the lee of the Longmynd rampart, as well illustrated by the uniform outcrop-curve of the Alberbury Breccia and the underlying massive sandstone across the main trough, is obscured locally at one stage in consequence of intense but selective denudation, which preceded a wide overstep by the Upper Coal Measures. That early denudation left in the Long Mountain, upon the axis of the syncline, where its folding was accentuated in crossing the curved pressure-belt, an elevated mass of late Silurian strata, at the foot of which Upper Coal Measures overlapped around its north-east end. But between the Long Mountain and the Longmynd it planed off the south-east limb of the fold down to the Archaean rocks, upon which the same Coal Measures abut on the east side. There, however, much denudation had been effected in pre-Silurian time (Fig. 4).

North-east of the Long Mountain the unconformable and overlapping Upper Coal Measures, with succeeding formations, may be regarded as slightly bent synclinally, upon successive renewals of earlier folding, in a vice of which the jaws were made by older rocks on both septal tracks of the old syncline. But eastward of the Long Mountain, where the south-eastern jaw had lost its inner part in exceptional degree by denudation, the western jaw of the vice as now affecting only the lower part of the local Upper Coal Measures was constituted by the Long Mountain itself in the trough of the original fold. Consequently those Coal Measures there make upon the south-eastern limb of that older syncline a complete but shallow independent syncline, which must open between north and north-east into the greater basin of uniform synclinal folding. The secondary syncline is separated on the west from the axial trough of the main syncline by a slight anticlinal curve of outcrop from a north-westward to a westward direction round the north-east corner of the Long Mountain at Westbury (Figs. 3 and 4).

This superficial anticlinal bend, due merely to the effect of the elevated mass, on to which those Coal Measures overlapped, upon their behaviour when renewal of the earlier movement increased the flexing of the irregularly denuded subjacent syncline, could not continue far. But it might initiate a line of weakness; and the Rowton Fault (Fig. 1), with westward downthrow and northward displacement of the Alberbury Breccia on its east side, may thus have developed along the north-west side of the push by that anticlinal 'nose' in the north-eastward resultant direction of movement.

A reasonable certainty that no corresponding anticline breaks the continuity of synclinal folding in the Silurian rocks under this little superficial anticline shows that the syncline of the Pontesbury coal-basin, as superimposed upon the south-east limb of the greater syncline, did not result from, though it was probably influenced by, a subordinate deformation of that limb in the underlying formations of its eastern part (Fig. 4). A minor syncline in the older strata apparently continues north-eastward under the east side of that basin, between the rise of the Longmynd and a prolongation of the subordinate Shelve Anticline,[1] and by its renewed flexing would presumably fix the trough of the superficial syncline on that side. But this was not the cause of general synclinal structure in these Coal Measures; for the broad western limb of their basin must have a dip contrary to that of the underlying formations (Fig. 4). The anticline, doubtless planed down under the Coal Measures, produced no perceptible effect upon them by any renewed upward flexing on the septal tract of major folding, when that tract was sinking towards the main synclinal trough under the Long Mountain. Such

[1] See C. Lapworth and W. W. Watts, 'The Geology of South Shropshire,' *Proc. Geol. Assoc.*, vol. xiii, 1895, Fig. 9, p. 314: also T. C. F. Hall, 'Report on the Shropshire Mining District,' 1919, Fig. 2, p. 11.

would be the case, if the mean curve of major folding was there not convex upward, but concave.

Northward displacement of the resistant Longmynd rampart would be accompanied throughout the ground farther west by similar displacement, increasing westward; for all but the north-east end of the Long Mountain lies outside any protective influence of the Longmynd in minimizing such displacement. While augmenting north-westward folding-pressure against resistance, it would entail corresponding northward transport of the Coal Measures upon a platform contracting in that direction also. Thus, instead of being simply tilted down north-westward on the south-east limb of the older syncline as its flexure increased, those measures were bent into a shallow independent syncline by pressure against the Long Mountain, which itself would have a tendency to compensatory elevation by the packing of material in its increased synclinal flexure. Moreover, meeting farther north the cumulative resistance of their own continuation where not thus squeezed, they would tend to screw round clockwise and ultimately to be torn off from that continuation by one or more faults. Such faults would take the general north-eastward resultant direction between northward force and south-eastward resistance in the Long Mountain, but would be modified by resistance on the north in some degree towards an eastward trend. This is no doubt why the Edge Fault, south of Yockleton (Figs. 1 and 3), and minor parallel faults in this secondary syncline have an east-north-eastward instead of a north-eastward direction.

Since northward displacement increased westward, while its effect upon these Coal Measures would be greater in proportion to their original extension southward where now removed by denudation, stresses in them would be greatest at the north-west corner of the tract affected by northward drive against south-eastward and southward resistances, all there at their maximum for this tract. There, on the east side of Westbury, a sort of block-brecciation was initiated. Between minor faults of several directions, of which northward and north-eastward trends are prominent, the latter as the resultant between northward force and south-eastward resistance, the former perhaps as a further resultant between this north-eastward force and north-westward pressure, the blocks themselves alternate the south-eastward strike of the basal measures in the west limb of the secondary syncline with the local eastward strike of higher measures immediately to the north in the main syncline (Fig. 3).

Farther east the clockwise twist imparted to these Coal Measures along the south side of the Edge Fault and facilitated by diminution of north-westward pressure owing to the north-eastward ending of the Long Mountain, warped them round in synclinal complement to their south-eastward rise on the slope of the Longmynd. Under this movement the development of the axial Rea Fault south-westward along the foot of that rise would initiate lateral displacement in that direction along the north-west

side, while further synclinal bending of the measures would tend to increase that displacement, otherwise inexplicable as to its direction. Thus, while the measures constituting the narrow south-eastern limb of the new superficial syncline came to dip north-west off the flank of the Longmynd on renewal of the older folding-movement, those of the broad north-western limb acquired a dip between north-east and east (Figs. 3 and 4). The appearance of great lateral movement along the Rea Fault is much exaggerated by the close approximation of its trend to strike for nearly half the distance on the south-east side, and by the comparatively slight inclination of the measures throughout.

That such was the actual genesis of this syncline in its northern part is indicated by the gradual eastward increase of divergence from the general eastward strike, with its ultimate curve to east-north-east, along the north side of the Edge Fault and within the main syncline, to a south-eastward strike in the secondary syncline on the other side, with the semblance of a slight faulted anticline developed locally between the two basins (Fig. 3). This return to parallelism with the basal strike of the measures south-eastward from Westbury evidences a continuity of structure obscured only by the ' block-brecciation ' in the north-western part of the superficial syncline.

The faults in the superficial syncline would not range far, and some may not descend below its Lower Palaeozoic floor. No trace of the Rea Fault has been detected in the older formations farther south-west.

Relation to the main syncline: adjustment by the Cardeston Fault.—With the failure of the Edge Fault beyond Yockleton the secondary syncline presumably opens out northward as an inlet of the main syncline, which hereabouts shows a slight south-eastward bulge of its higher synclinal outcrops. The considerable southward displacement on the east side of the inferentially earlier Cardeston Fault suggests on that side a later southward movement complementary to the southward clockwise twist on the north-west side of the Rea Fault. But since the Cardeston Fault, which like one other of the septal tension-faults (pp. 9, 12), has a downthrow away from the main synclinal axis, evidently cannot continue far south of Yockleton, the appearance of lateral movement is presumably exaggerated by uneven depression on its east side.

Conversely, the east-north-eastward curve of outcrop in the main syncline on the west side of the same fault at Yockleton shows, where north-eastward pressure in the secondary syncline would be effective, an appreciable northward displacement with constriction of outcrop in the main syncline below the Alberbury Breccia. It may be significant too that this fault, in its northern part as mapped, curves with eastward convexity as though warped by the north-eastward push on the north-west side of the wedge between it and the Rowton Fault.

Thus it appears that, as in North Wales, the same mechanical principles, not obscured by complexity of detail, are capable of interpreting here the main features of Palaeozoic and later tectonic structure, where the periodic yielding of the earlier Longmynd rampart and the eastward diversion of the massive Berwyn Anticline under torsion played a prominent part by their interaction.

II.—*LABECHIA CARBONARIA* SP.NOV., A LOWER CARBONIFEROUS STROMATOPOROID FROM WEST CUMBERLAND

BY

STANLEY SMITH, M.A., D.Sc., F.G.S.

Plate I.

INTRODUCTION

THE Stromatoporoidea (Nicholson and Murie, 1878, p. 241) range from early Palaeozoic, possibly Cambrian,[1] to at least Mesozoic[2] time. They are conspicuous fossils and important rock builders in the Ordovician, Silurian and Devonian systems, attaining their highest development in the Silurian and Devonian, yet, except at the very base, appear to be exceedingly rare in the Carboniferous system. Professor O. H. Schindewolf informs me that Stromatoporoids are very abundant at the Étroeungt Stage, the Transition Stage between the Famennian and the Tournaisian around Aachen, Germany, and has very kindly sent me specimens of some of these. C. Dantz, 1893, p. 624, pl. xxviii, figs. 1a, 1b, has described and figured a *Clathrodictyon, C. aquisgranense,* from this locality and horizon, and G. Gürich, 1904, pp. 1-5, pl. i, a *Stromatoporella, S. cracoviensis,* from Dembnik near Cracow, Poland, probably from the same level.[3] Beyond these I know of no other unquestionable Stromatoporoids that have been described from Carboniferous rocks.[4] Recently, however, a species of *Labechia* for which I

[1] W. A. Obrutschew, 1926, pp. 64-65, 86-9 and 109, records Stromatoporoids from Lower, Middle and Upper Cambrian beds of Siberia, although in some places doubtfully so. However, since he gives neither figures nor descriptions, it is impossible to form an opinion concerning the real nature of the fossils he collected.

[2] Numerous hydrozoans from Permian, Trias, Jurassic, Cretaceous, and even Tertiary formations have been referred to the Stromatoporoidea. It is clear that many of these do not belong to the class, but at the same time there are others whose Stromatoporoid affinities can hardly be questioned. It would be entirely out of place, and without carefully revising the material most inadvisable, to discuss the fossils here, but the following works describing some of these may be cited uncritically. Bakalow, 1906, 1910, Deninger, 1906, Osimo, 1911, Parona, 1909, Weissermel, 1926, Yabe, 1903, Yabe and Sugiyama, 1930[a], 1930[b].

[3] Gürich does not mention precisely the horizon at which his Stromatoporoid was found, but Czarnocki, 1928, p. 209, in the classification of the Lower Carboniferous in the eastern Region of the Polish Coal Basin, after Jarosz, places 'Limestones with Stromatoporoids' in the Étroeungt Stage at the base of the Tournaisian and makes the stage the equivalent of the *Cleistopora* zone of Vaughan.

[4] Waagen and Wentzel, 1887, pp. 925-994, pls. cxxvii-cxxviii, have described several genera of hydrozoans (*Carteria, Disjectopora, Irregulatopora,* and *Circopora*) from the *Productus* Limestone (Permo-Carboniferous) of the Salt Range, India, and place them near the Stromatoporoids. Although the forms are undoubted Hydrozoa, their Stromatoporoid affinities are at least uncertain. See Gürich, *op. cit.* Girty 1908, p. 40; 1913, p. 313, pl. xxvii, figs. 4, 5, has described under the name *Carnegiea bassleri* a fossil from the Pennsylvanian of China which he considered a new Stromatoporoid, but both figure and description of the form suggest a tabulate coral with very small corallites rather than a hydrozoan.

The 'Spongiostromides' described by Gürich, 1906, pp. 1-56, pls. i-xxi, from the Viséan of Belgium, regarded by him as Protozoa but now generally admitted to be algal, have been referred to the Stromatoporoidea by some writers, e.g. T. W. Vaughan in Zittel-Eastman, 1913 (although with some doubt), and A. W. Grabau, 1921, p. 465.

propose the trivial name *carbonaria* has been found in high Viséan beds in the north-west of England. The specimens were obtained by Mr. A. Templeman, of the Geological Survey, from the cores of three boreholes put down by the Beckermet Mining Company near Hale, 7 miles S.E. of Whitehaven, West Cumberland, and were submitted to me together with the corals from these cores for determination. They were nodules obviously of organic origin although their precise nature was not discovered until thin sections of material had been prepared. All the nodules were complete, but being embedded in matrix failed to show the external features of the colonies. Fortunately the internal structures are well preserved.

The borings, which penetrated the Carboniferous Limestone below a thick covering of New Red Sandstone (Permo-Trias), encountered the *Labechia* near the middle of the Seventh Limestone, in a series of fine-grained limestones and calcite mudstones, in beds varying in thickness up to fifteen inches and separated by films of marl. The specimens of *Labechia carbonaria* were all obtained within a vertical range of less than twenty-five feet. Details of the borings are given below. The higher beds of Avonian age are not met with in these borings; in fact, in Borehole 33 only part of the Seventh Limestone is present. The Carboniferous floor rises northwards and reaches the surface at Egremont—a short distance of 2 miles away.

	No. 33 Borehole 500 yds. N. by E. of Hale Church		No. 34 Borehole 600 yds. S. by W. of Hale Church		No. 35 Borehole 200 yds. E.S.E. of Borehole 34	
	Ft.	In.	Ft.	In.	Ft.	In.
Drift	20	0	28	0	11	6
New Red Sandstone—						
St. Bees Sandstone	768	0	987	0	1,129	0
Brockram	206	3	259	0	292	6
Unconformity						
Lower Carboniferous—						
Fourth to Sixth Limestone ...	——		210	0	150	9
Seventh Limestone (and basement beds)	127	9	186	0	187	6
Ordovician—						
Borrowdale Series—volcanic ash	11	0	15	0	9	9
Labechia proved at	1,049	0	1,580	0	1,676	0
Base of Carboniferous proved at ...	1,122	0	1,670	0	1,771	3
Height of *Labechia* above base ...	73	0	90	0	95	3

The Lower Carboniferous succession in West Cumberland has recently been described by E. E. L. Dixon in the memoir on the Whitehaven and Workington District published by the Geological Survey, but it may be mentioned here that the sequence in that part

of the county is entirely Upper Viséan. The Seventh Limestone (at the base of the series) has been referred both by C. Edmonds, 1922, p. 127, and E. E. L. Dixon, *op. cit.*, p. 76, to the higher part of the Seminula Zone (S_2) of A. Vaughan, 1905, p. 186 (=*Nematophyllum minus* subzone of E. J. Garwood, 1912, p. 452), and this correlation is probably correct. The horizon is a shallow-water formation built up of arenaceous limestones, calcareous sandstones, fine-grained limestones and calcareous mudstones. Some limestones are rich in gasteropods, while others contain little else but ostracods. The coral and brachiopod fauna is a very meagre one, but such species as have been found indicate the uppermost part of S_2 rather than the lowest part of D_1 (Lower Dibunophyllum Zone), although the horizon might be more correctly regarded as the transitional one between the Seminula and Dibunophyllum Zones. *Dibunophyllum* is present and so also is *Lonsdaleia duplicata* (Martin).[1]

The circumstances under which the type material of *Labechia carbonaria* were found led one to infer, or at least to suspect, the existence of a definite and probably persistent band of the Stromatoporoid, which might be sought for north of Egremont where the Seventh Limestone is exposed. It seemed reasonable to suppose that the fossil had not been noticed before because of the obscure character of the coenostea, which might well be overlooked or mistaken for colonies of *Chaetetes* or thalli of a calcareous alga. It is therefore of interest to note that Mr. Charles Edmonds has since then sent me a specimen of *L. carbonaria* which he has collected from the same horizon and in similar beds at Frizington Parks, a few miles to the north of Hale. This specimen has been cut into two portions, one of which is presented by Mr. Edmonds to the British Museum (Nat. Hist.), the other to the Geological Survey (numbered 50264).

In preparing this paper, I have received help from several friends, and to these I tender my thanks: to Dr. F. L. Kitchin for providing me with the materials of research; to Dr. W. D. Lang for the loan of additional specimens of *L. conferta* in the British Museum, and for access to Nicholson's collection of Stromatoporoids (which contains his types); to Mr. A. Templeman for supplying me with the details concerning the Hale borings; to Dr. H. D. Thomas for his assistance with the literature; and to Dr. R. S. Bassler, Mr. Charles Edmonds, Professor Franz Heritsch, and Professor O. H. Schindewolf for communicating useful information. Dr. Kitchin has also edited my MS.

Before describing the new form it is necessary to consider first the genus *Labechia* and its genotype *L. conferta* (Lonsdale), and to remark upon the special features exhibited by certain other species.

[1] I have found *Lonsdaleia duplicata* near the top of the Seminula Zone near the Suspension Bridge, Clifton.

The Genus and the Genotype Species

Labechia

Labechia Edwards and Haime, 1851, p. 279; *Labecheia* Edwards and Haime, 1854, p. 269; *Labechea* Eichwald, 1860, p. 491; *Lebechia* Scudder, 1882, p. 181.

Genotype: by monotypy, *Monticularia conferta* Lonsdale, 1839, p. 688, pl. xvi, figs. 5, 5a. Silurian, Wenlock Limestone. Benthall Edge and Gleedon Hill, near Wenlock.

Diagnosis. — Stromatoporoidea with lamellar or massive coenostea and stout, erect and continuous pillars united by curved or straight transverse plates, but without astrorhizae.

Remarks.—Labechia is distinguished from other Stromatoporoids by its very strong, straight, radial pillars, which continue upwards through the coenosteum without a break and stand out from the distal surface as tubercles. Usually they do not branch. They are perforated by an axial canal although apparently solid at their apices. Typically the under surface of the coenosteum is covered by a concentrically wrinkled basal epitheca and shows a cone of attachment not necessarily near the centre.

Edwards and Haime founded the genus for Lonsdale's '*Monticularia conferta,*' which they considered to be a tabulate coral belonging to the 'Chaetetinae,' a group of heterogeneous genera established by them to include forms which they thought had no mural pores. Duncan, 1872, p. 128, made *Labechia* a sub-genus of *Monticulipora* (d'Orbigny, 1850, p. 25). Lindström, 1873, p. 20; 1876, pp. 4, 16, pointed out its hydrozoan characters and suggested removing it from the Anthozoa, and Roemer, 1883, p. 543, placed the genus (in which he included besides '*L. conferta* (Lonsdale)', *Stromatopora dentata* Rosen, 1876, p. 75) in the Stromatoporoidea. But it should be made clear that these two authors interpreted *L. conferta* incorrectly by using another Stromatoporoid—*Lophiostroma schmidtii* (Nicholson), 1886[2], p. 16, pl. ii, figs. 5-8; 1891, p. 160 (footnote), which shows an entirely different structure from that of *Labechia.* Nicholson, 1879, p. 330, retained *Labechia* among the Tabulate corals, but in 1886[1], p. 81, followed Roemer in transferring it to its present systematic position. In the third part (1891) of the same work, pp. 160-164, he described several new and interesting species of *Labechia,* including Ordovician and Devonian forms. M. Heinrich, 1914[1], pp. 733-734, advocates removing the Labechidae and the Idiostromidae from the Stromatoporoidea on account of differences in their structure from that of the more typical genera[1], and his view is partly supported by Yavorsky, 1931, p. 1405.

Geological and Geographical Range.—Ordovician: Europe—Britain, Esthonia (Nicholson); Asia—N. China, S. Manchuria,

[1]This paper anticipates remarks in a Dissertation (1914[2]) which I have not seen.

Corea (Yabe and Sugiyama); North America—U.S.A. and Canada (Nicholson and others)[1]. Silurian: Europe—Britain, Gotland (Nicholson); Asia—Siberia (Schmidt, also Riabinin). Devonian: Europe—Devonshire (Nicholson). Carboniferous: Europe—Cumberland.

Labechia conferta (Lonsdale)

Plate I, figs. 1-7.

Monticularia conferta Lonsdale, 1839, p. 688, pl. xvi, figs. 5-5a.

Labechia conferta (Lonsdale) Edwards and Haime, 1851, p. 280.

Labecheia conferta (Lonsdale) Edwards and Haime, 1885, p. 269, pl. lxii, figs. 6, 6a-c.

Labechia conferta (Lonsdale) Nicholson, 1879, p. 330, text-fig. 44 on p. 331; pl. xv, fig. 4: 1886-92, pp. 81, 158, text-fig. on p. 82; pl. iii, figs. 7-15[2]; pl. xx, figs. 1-3.

Non *Labechia conferta* (Lonsdale) Roemer, 1883, p. 542, text-fig. 126, which is *Lophiostroma schmidtii* (Nicholson).

Only critical works and other publications giving good descriptions and figures are mentioned in the above brief synonymy.

Diagnosis.—*Labechia* with laminar coenostea and stout radial pillars which seldom branch and are united by convex plates.

Description.—The coenosteum is typically low and spreading and is usually built up of superposed layers. It is often very irregular in outline, has an undulating distal surface and a flat, concave, or sometimes obtusely conical lower surface. Coenostea attain a diameter of one foot and a thickness of an inch or more, but smaller colonies only a few centimetres in diameter and a centimetre or less in thickness are more common. The distal ends of the radial pillars stand out prominently above the otherwise smooth upper surface as closely set, rounded tubercles. These tubercles may be evenly distributed (Pl. I, fig. 1) or arranged in a labyrinthine pattern (Pl. I, fig. 3). The lower surface is covered by a strong basal epitheca concentrically wrinkled about the cone of attachment, which is by no means always centrally placed.

[1] Parks, W. A., 1907, p. 20, describes *Labechia durhamensis*, pl. ii, figs. 4-6; pl. iii, fig. 1; pl. iv, figs. 1 & 2, and *L. minora*, pl. iii, figs. 2, 5 and 6, from the Niagaran of Ontario; but these species are said to have irregular bars instead of plates. It seems doubtful, therefore, whether these can be retained under *Labechia*.

[2] Figs. 9-11 represent a small, perfectly circular, discoid coenosteum which Nicholson believed to be a young colony, but which Miss M. S. Johnston, 1915, p. 433, considers to be another species of *Labechia* (*L. rotunda* Johnston, *loc. cit.*).

The radial pillars, which are between ·3 and ·5 mm. in diameter and are separated by average distances equal to the diameter of the pillars, are circular in transverse section (Pl. I, fig. 5), but appear serrate when viewed longitudinally (Pl. I, fig. 7). They are perforated by axial canals, although the canal is not always obvious. The transverse tissue between the pillars consists of thin convex plates, which resemble in longitudinal sections the dissepiments of a rugose coral (Pl. I, fig. 7). Intersections of these strongly arched plates are occasionally seen in transverse section joining two pillars. This led Lonsdale to assume the presence of septa in *Labechia*; his otherwise correct though brief description of the species reads: ' M. Encrusting or expanded in lobes; central axis *close-set,* irregular in size, yet large in proportion to the distance between them; round when single, but several are often united; indications of radiating lamellae few; under surface when free, uneven, smooth or marked by irregularities of growth.'

The neotype of *L. conferta* (here chosen), Pl. I, figs. 1 and 2 (specimen 28183 in the Museum of Practical Geology, section M/834, Wenlock Limestone, Benthall Edge; from the Geological Society's Collection) is a small, irregularly shaped coenosteum 6 cm. long, 3·5 cm. wide and ·5 thick, attached to a corallite of *Xylodes articulatum*[1]. The under surface (Pl. I, fig. 2) is covered by the usual basal epitheca, but the cone of attachment is concealed by the coral on to which it has cemented itself. The upper surface (Pl. I, fig. 1) is partly hidden by other organisms, but where free from matrix shows the features characteristic of the species. The tubercles are on the whole evenly distributed, though some tendency towards a labyrinthine arrangement is noticeable.

Remarks.—Labechia conferta has closely set, regularly formed radial pillars and highly vesicular transverse tissue. In most other species of *Labechia* the horizontally disposed plates are flatter.

Horizon and Localities.—Silurian; Salopian. *L. conferta* has been found in most localities in Britain where the Wenlock Limestone is typically developed; Wenlock, Coalbrookdale, Malverns, Mayhill, etc.; it also occurs at the same horizon in Gotland. Schmidt, 1872, p. 17, records the species from N.E. Siberia, but it is not figured or described by him.

Notes on certain other Species of Labechia

The labyrinthine arrangement of the pillars seen in *L. conferta* is much more highly developed in the Devonian *L. serotina* Nicholson (1886[2], p. 15, pl. ii, figs. 3 and 4; 1889, p. 162, text-fig.).

[1] The specimen was presented to the Geological Society by Sir R. I. Murchison, and is possibly one of Lonsdale's syntypes.

Here the pillars are united into sinuous chains of laterally contiguous individuals, somewhat resembling the coral *Halysites*. The transverse plates in *L. serotina* are flat and very distant. In *L. stylophora* Nicholson (1889, p. 161, pl. xx, figs. 7 and 8), another Devonian species, the radial pillars are grouped into cylindrical bundles about 8 or 9 mm. in diameter. *L. ohioensis* Nicholson (1886[1], p. 83, pl. ii, figs. 1 and 2; 1886[2], p. 13, pl. ii, figs. 1 and 2), Ordovician, North America, resembles *L. conferta* very closely in its vesicular tissue, but this is finer, and the pillars which are of smaller diameter are angular in cross section and are more widely spaced.

The new Carboniferous Species

Labechia carbonaria sp. nov.

Plate I, figs. 8-12.

Diagnosis.—*Labechia* with massive coenostea, and radial pillars which frequently branch and are connected by concave plates.

Description.—The whole of the material at present available comprises only a few incomplete coenostea embedded in limestone and superficially silicified and corroded. The external characters of the species are thus imperfectly known. The internal structures on the other hand are very well preserved.

The coenosteum is spheroidal, of irregular shape or discoidal in form, and possibly attains considerable size. The holotype 51516 (Pl. I, figs. 10-12) is part of a spherical or spheroidal colony at least 7·5 cm. in diameter; the paratype 51517 is part of a tall coenosteum, and the paratype 51514 is part of what appears to be a very irregular sheet. The surface characters are not known.

The radial pillars, which are about ·2 to ·3 mm. in diameter, are separated by distances averaging ·5 mm. They are straight, almost erect, but repeatedly bifurcate, and the branches diverge at a small angle. Their sides are very uneven and their transverse sections are circular to angular, and often of irregular shape. Traces of an axial canal can sometimes be detected. There is no very definite arrangement of the pillars; in some places they are more closely clustered together than in others, and there form small groups of contiguous individuals, usually the branches of a common parent branch (Pl. I, fig. 11). The transverse plates are very thin and are concave or nearly flat, and usually a single plate bridges the interval between two pillars; they are irregularly spaced, but an average distance between them is ·1 mm. or little more.

Remarks.—*Labechia carbonaria* is distinguished from its congeners by its branching radial pillars. In other respects its characters are very ordinary. It differs from *L. conferta* (Lonsdale) in the massive character of its coenosteum, its thinner, less symmetrical radial pillars, and its flatter, concave transverse plates. On the other hand the pillars in *L. carbonaria* are stouter than those in *L. serotina* (Nicholson) and in *L. ohioensis* (Nicholson), and are not so angular as those of the latter. The transverse section through the coenosteum somewhat resembles that of *L. variabilis* Yabe and Sugiyama, from the Ordovician of N. China, S. Manchuria, and Corea, as illustrated by their figure (1930, pl. xvii, fig. 1).

Horizon and Locality.—Carboniferous, Viséan, top of the Seminula Zone (S_2), Hale and Frizington Parks, West Cumberland (see pp. 24, 25).

Specimens: In the Museum of Practical Geology; in the British Museum (Nat. Hist.).

Holotype: 51516 (section M/831). Borehole No. 34, Hale, depth 1580 ft.

Paratypes: 51514 (sections M/828, M/829); 51515 (section M/830); Ba 2990, a fragment used up in investigation; all from Hale, Borehole No. 33, depth 1049 ft.: 51517 (sections M/832, M/833), Hale, Borehole No. 34, depth 1580 ft.: 51518 and section, a poorly preserved fragment, Hale, Borehole 35, depth 1676 ft.

There is the further specimen found more recently by Mr. Charles Edmonds at Frizington Parks. As remarked above, this has been divided into two portions, one of which has been presented by Mr. Edmonds to the British Museum (Nat. Hist.), numbered H. 3163, the other to the Geological Survey, numbered 50264.

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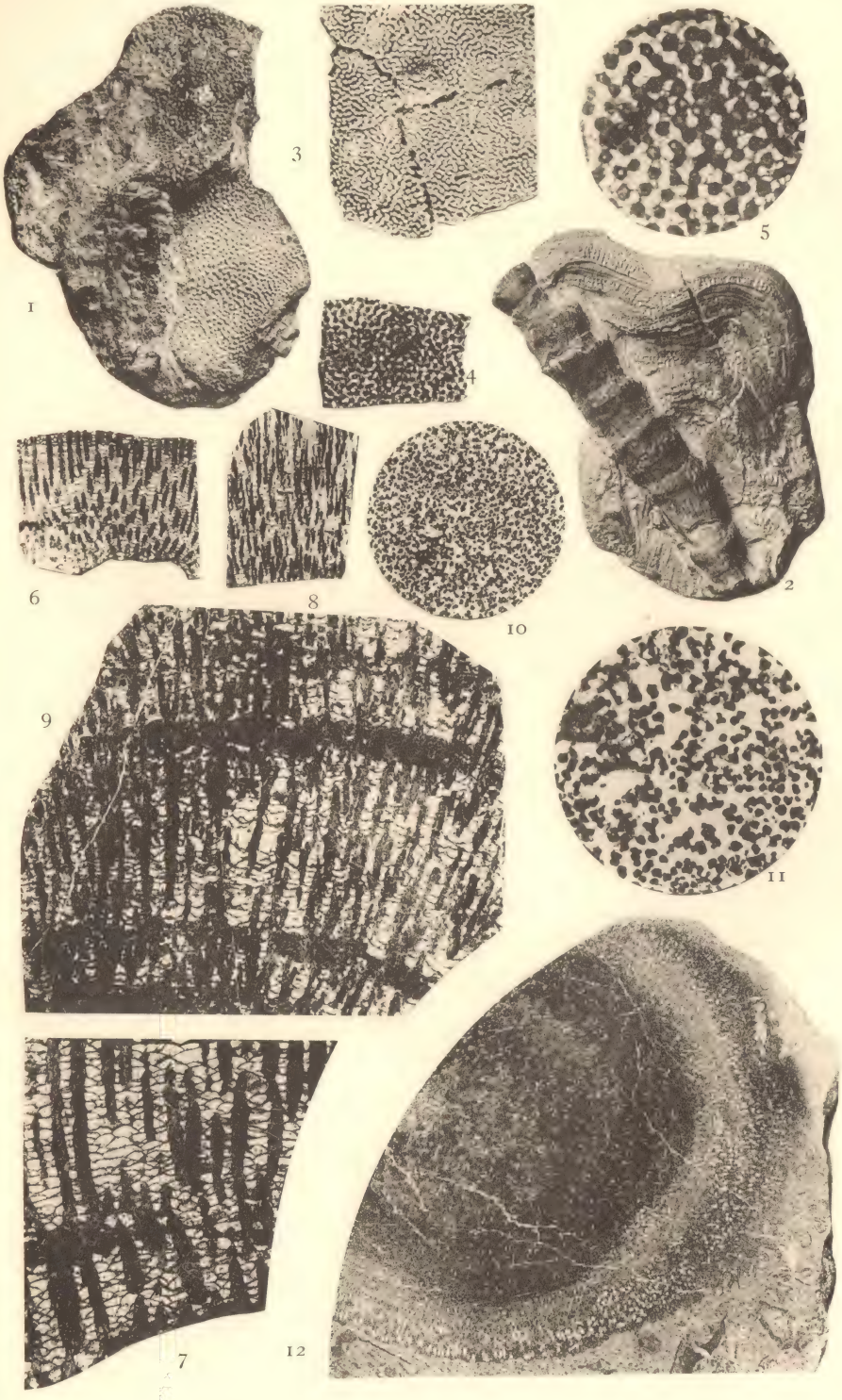

J. E. Livingstone, photo.

LABECHIA CONFERTA (LONSDALE) AND *LABECHIA CARBONARIA* SP. NOV.

Explanation of Plate I

All specimens and sections, except the originals of figs. 4 to 7, are in the collection of the Geological Survey.

Labechia conferta (Lonsdale), Silurian, Wenlock Limestone. Page 27.

Fig.

1. Distal surface, natural size, Benthall Edge, near Wenlock. Neotype, 28183.
2. Proximal surface of the same specimen, natural size.
3. Distal surface showing the labyrinthine arrangement of the radial pillars, natural size. Wenlock Edge. Specimen 51489.
4. Transverse section of a specimen in Bristol University, Purlieu, Malvern; × 1.5.
5. Transverse section of another specimen in Bristol University, from the same locality; × 4.
6. Longitudinal section cut from specimen H.3175 in the British Museum (Nat. Hist.), G. H. Morton Coll., Coalbrookdale; section H.3176, × 1.5.
7. Longitudinal section cut from the same specimen, H.3175; section H.3177, × 4.

Labechia carbonaria sp. nov., Carboniferous, Viséan, top of the Seminula Zone (S_2), Hale, West Cumberland. Page 29.

8. Longitudinal section M/832, × 1.5; cut from paratype 51517. Borehole 34, depth 1580 ft.
9. Longitudinal section M/828, × 4; cut from paratype 51514. Borehole 33, depth 1049 ft.
10. Transverse section M/831, × 1.5; cut from the holotype, 51516. Borehole 34, depth 1580 ft.
11. The same transverse section, M/831, × 4.
12. The holotype, 51516. Part of the coenosteum embedded in limestone, natural size. Borehole 34, depth 1580 ft.

III.—THE MILLSTONE GRIT SUCCESSION IN NORTH STAFFORDSHIRE

BY

S. W. HESTER

Text-figure 1.

INTRODUCTION

DURING recent years, since the establishment of Bisat's zonal classification,[1] the study of the Millstone Grit has acquired renewed impetus. North-east Staffordshire has already received some attention,[2] and here an effort is made to place on record the results of a preliminary investigation of some Lower Coal Measure and Millstone Grit fossils, mainly from the north-west portion of that county. The bulk of the material examined was collected by D. Tait during the survey of the Macclesfield, Congleton and Crewe district (Sheet 110, 1906). The collection of the late Dr. Wheelton Hind, now deposited at the Natural History Museum, has also been investigated.

In previous accounts the strata between the Coal Measures and Carboniferous Limestone of North Staffordshire are classified as Millstone Grit and Pendleside Series or Yoredale Group.

The term Pendleside Series has suffered many vicissitudes in recent years and the name Pendleside has now been restricted in use to the limestone and grit occurring towards the top of the Lower Carboniferous in Lancashire.[3] The Yoredale Group is still a subject of discussion which will not be pursued here, since the division is considered to be absent in Derbyshire, and no evidence is forthcoming that it is developed in the area now under review.

GENERAL SUCCESSION

The Carboniferous succession of North-east Staffordshire has been summarized as follows[4]:—

5. Goldsitch Coal Measures (Lower Coal Measures)
4. The Roches Grits
3. The Churnet Shales
2. The Morredge Grits
1. The Mixon Limestones (Carboniferous Limestone and Limestone Shales)

[1] Bisat, W. S., 'The Carboniferous Goniatites of the North of England and their Zones,' *Proc. Yorks. Geol. Soc.*, vol. xx, 1923-26, pt. 1, 1924, p. 40 *et seq.*

[2] Challinor, J., 'Notes on the Geology of the Roches District,' *Trans. North Staffs. Field Club*, vol. lv, 1920-21, pp. 76-87; 'Notes on the Geology of the Mixon District,' *ibid.*, vol. lxii, 1927-28, pp. 96-109; 'Notes on the Geology of the North Staffordshire Moorlands,' *ibid.*, vol. lxiii, 1928-29, pp. 111-113; 'The Stratigraphical Position of the Roches "Rough Rock,"' *ibid.*, vol. lxiv, 1929-30, pp. 41-42.

[3] In 'Handbook of the Geology of Great Britain' (Edited by J. W. Evans and C. J. Stubblefield), 1929, Figs. 28a and 30.

[4] Challinor, J., *op. cit.*, 1928-29, pp. 111-113.

R. Kidston also published a section designed to represent the succession of these rocks in North Staffordshire.[1] This section (see p. 43) was compiled by Dr. Walcot Gibson, and the following beds are shown in descending order :—

First Grit
Shale
Third Grit
Shale
Fourth Grit
Shale
Fifth Grit
Shales with sandstones, calcareous mudstones, thin earthy limestones, and quartzitic sandstones
Carboniferous Limestone

General Structure

A brief description of the general arrangement of the Carboniferous rocks of the district is necessary. The Carboniferous Limestone along the eastern boundary is the western flank of the main Pennine Anticline. The beds succeeding the limestone flatten in dip, and occupy a long syncline which forms the southern continuation of the structure termed the ' Goyt Trough ' by Farey[2] from the River Goyt which flows along the northern part of the synclinal axis. Minor folding occurs and inliers of limestone are found at Mixon and Butterton. To the west is a less steeply dipping synclinal called by Hull and Green the ' Rudyard Basin,'[3] and farther west is the syncline known as the ' Biddulph Trough,' the crests of the western and eastern limbs of the latter being Congleton Edge and Lask Edge respectively. The Carboniferous Limestone is brought up again at Astbury on the western extremity of the area, along which runs the Red Rock Fault, throwing down the Trias against the Carboniferous.

The district may thus be conveniently divided into four areas, and the accompanying table illustrates the goniatite zones that have now been recognized within them (Table A).

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[1] Kidston, R., ' Fossil Plants of Carboniferous Rocks of Great Britain ' (*Mem. Geol. Surv.*, Palaeontology, vol. ii), 1923, Pl. A, p. 10.

[2] Farey, J., 'General View of the Agriculture and Minerals of Derbyshire,' 1811, vol. i, p. 172.

[3] Hull, E., and A. H. Green, ' On the Millstone Grit of North Staffordshire and the adjoining parts of Derbyshire, Cheshire and Lancashire,' *Quart. Journ. Geol. Soc.*, vol. xx, 1864, p. 243.

TABLE A.—GONIATITE HORIZONS RECOGNIZED IN THE MILLSTONE GRIT OF NORTH STAFFORDSHIRE.

Zone	Horizons recognized	Biddulph Syncline		Rudyard Basin	Goyt Trough and Cheadle
		West Limb	East Limb		
G	Gastrioceras listeri (*Martin*)		Woodhouse Colliery		Consall Wood Blackbank Brook
	,, *cf.* subcrenatum (*Schlotheim*) ...		Biddulph Grange		
	,, cancellatum *Bisat*	Timbersbrook	Crowboro' Wood		Gib Torr Farm[3]
R_2	Reticuloceras reticulatum (*Phill.*), *mut.* bilingue (*Salter*) [late form]				R. Churnet[3]
	,, ,, (*Phill.*), *mut.* bilingue (*Salter*) ...			R. Dane	R. Churnet[3]
	,, ,, (*Phill.*), early *mut.* bilingue (*Salter*)			R. Dane	Harston Wood
	,, ,, (*Phill.*), *mut.* gracile *Bisat*				Star Wood Felt House Wood
R_1	,, ,, (*Phill.*), type form ...		Spring House	R. Dane Shell Brook	
	,, inconstans (*Phill.*)	Corda Well	Dingle Brook	Shell Brook	
H	Homoceras proteum (*Brown*); H. smithi (*Brown*)	Congleton Edge Puddlebank	Dingle Brook		
	,, *aff.* undulatum (*Brown*) ...			Shell Brook	
	,, striolatum (*Phill.*), *cf. var.* subglobosum (*Brown*)				Blacksmith's Arms
E_2	Eumorphoceras bisulcatum *Girty*...		Hollywood Dingle[2]		R. Churnet[3] R. Hamps[4]
	Cravenoceras stellarum *Bisat*[1]				Cheddleton B.H.
E_1	Eumorphoceras *aff.* pseudobilingue *Bisat* ...				Waterhouses Sta.[4]

[1] Considered by W. S. Bisat to be near horizon of *C. edalense* Bisat. [2] *Anthracoceras paucilobum* (Phill.) only collected.
[3] Recorded by J. Challinor (*op. cit.*, 1928-1929, p. 112, and 1929-1930, p. 42). [4] Recorded by W. S. Bisat (*in litt.*).

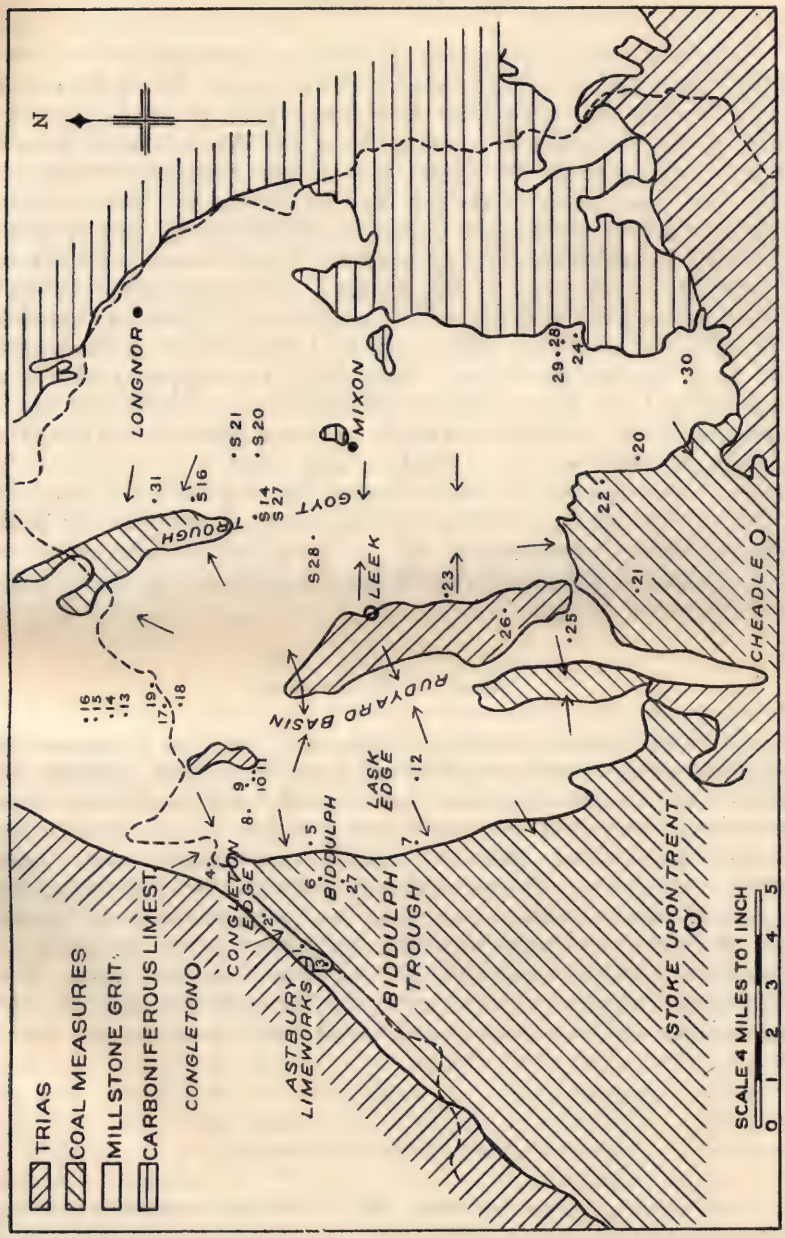

FIG. 1.—*Sketch-map of North Staffordshire, illustrating the general dip of the Millstone Grit. Modified from Hull and Green, 1864, and W. Gibson, 1908. The numbers refer to localities listed on pp. 46-48.*

Palaeontological Notes

Zone of Eumorphoceras

The lower part of this zone (E_1), as yet unrecognized in Derbyshire, has been proved in North Staffordshire by W. S. Bisat, who has collected and identified *Eumorphoceras* aff. *pseudobilingue* Bisat from the railway cutting west of Waterhouses Station.[1] Definite evidence of the upper part of the Eumorphoceras Zone has been previously recorded by J. Challinor,[2] who collected *Eumorphoceras bisulcatum* Girty, *Posidonomya* aff. *membranacea* (M'Coy), *Pseudamusium* cf. *praetenuis* (von Koenen), and *Pterinopecten* aff. *rhythmicus* J. W. Jackson, from the River Churnet. From a boring at Cheddleton Paper Mills W.S. Bisat has identified *Cravenoceras stellarum* Bisat, which is found with *Anthracoceras sp.* and *Posidonomya sp.*, indicating the upper part of the Eumorphoceras Zone. *Eumorphoceras sp.*, *Anthracoceras* cf. *glabrum* Bisat and *Posidonomya* cf. *membranacea* (M'Coy) are recognized from north of Caldon, and from a shale scar in the River Hamps west of Waterhouses Station W. S. Bisat has collected *Eumorphoceras bisulcatum* Girty. *Anthracoceras paucilobum* (Phill.), identified by W. S. Bisat and considered by him to be typical of the upper part of the Eumorphoceras Zone, occurs in Hollywood Dingle.

Zone of Homoceras

The well-known marine horizon of Congleton Edge containing *Homoceras proteum* (Brown) and *H. smithi* (Brown) falls within this zone. A rich brachiopod and molluscan fauna (previously recorded[3]) occurs above and below the goniatite bed. *Homoceras proteum* (Brown) is also to be found near Puddlebank. A form of *Homoceras*, specifically indeterminable, from Dingle Brook, Rushton, occurring just below beds with '*Orthis*' *sp.*, probably represents the same horizon. A marine band with *Homoceras striolatum* (Phill.), cf. var. *subglobosum* Bisat[4] occurs in a railway cutting 2 miles south-south-east of Leek, while *Homoceras* aff. *undulatum* (Brown) has been recognized by W. S. Bisat from Shell Brook.

Zone of Reticuloceras

The lower part of this zone (R_1) contains marine bands with *Reticuloceras inconstans* (Phillips) and *Reticuloceras reticulatum*

[1] The localities mentioned on this and succeeding pages are shown on the map (p. 37) by numerals, the key to which appears on pp. 46-48.
[2] Challinor, J., *op. cit.*, 1928-29, p. 112.
[3] Wheelton Hind, 'Geology in the Field,' Chap. xxiv (Staffordshire), 1910, pp. 578-9.
[4] Identification confirmed by Mr. W. S. Bisat.

(Phillips). There is strong evidence of the former horizon, which is to be seen just below Congleton Edge, at the northern end of Lask Edge and in Shell Brook. *Pterinopecten rhythmicus* J. W. Jackson and *Posidoniella minor* (Brown), elongate variety, have also been recognized. *Reticuloceras reticulatum* (Phillips) is found near Spring House, in the River Dane, and in Shell Brook. The Shell Brook marine band contains *Reticuloceras* cf. *coreticulatum* Bisat and *Homoceras striolatum* (Phillips), which indicates a lower horizon than that of Spring House, where *Reticuloceras reticulatum* (Phill.) is associated with forms near *R. reticulatum* (Phill.), mut. *gracile* Bisat. Other fossils from the lower horizon are *Posidoniella laevis* (Brown), *Dimorphoceras sp.*, *Orthoceras sp.*, and *Temnocheilus sp.*

From the upper division of the Reticuloceras Zone (R_2), *Reticuloceras reticulatum* (Phillips), mut. *gracile* Bisat has been recorded from Star Wood,[1] and it is also to be found at Felt House Wood, south-south-west of Leek. Early forms of *R. reticulatum* (Phillips), mut. *bilingue* (Salter) are found at Harston Wood and the River Dane. *R. reticulatum* (Phill.), mut. *bilingue* (Salter) occurs in the River Dane (Fall Wood) and has been recorded from the River Churnet.[2] *Pterinopecten* cf. *speciosus* J. W. Jackson, *Pt.* cf. *elegans* J. W. Jackson and *Posidoniella* cf. *rugata* J. W. Jackson are also found.

Zone of Gastrioceras

Gastrioceras cancellatum Bisat associated with *Reticuloceras reticulatum* (Phillips), mut. *superbilingue* Bisat, indicating the base of this zone, are found at Timbers Brook on the northern edge of the Biddulph Syncline and in Crowborough Wood on its eastern limb. At the former locality *Gastrioceras cancellatum* Bisat, var. *crencellatum* Bisat, *Pterinopecten elegans* J. W. Jackson, and *Posidoniella* cf. *multirugata* J. W. Jackson also occur. The Crowborough Wood marine band contains limestone nodules with goniatites preserved in solid form; unfortunately, these are almost entirely devoid of external ornament. *Gastrioceras* cf. *cancellatum* Bisat, *G. crenulatum?* Bisat, *G. cancellatum* Bisat, cf. var. *crencellatum* Bisat, cf. *Homoceras proteum* (Brown) and *Reticuloceras reticulatum* (Phillips), mut. *superbilingue* Bisat,[3] can be recognized. It is of special interest to find the last named species in solid form, as very few examples are known. In the shale associated with the ironstone, *Gastrioceras sp.*, *R. reticulatum* (Phill.), mut. *superbilingue* Bisat, and *Pterinopecten* cf. *elegans* J. W. Jackson occur.

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[1] Bisat, W. S., *op. cit.*, 1924, p. 117.

[2] Challinor, J., *op. cit.*, 1928-9, p. 112. [*R. reticulatum* (Phill.) recorded from locality S 16 has been amended to *R. reticulatum* (Phill.), cf. mut. *bilingue* (Salt.) by J. Challinor. Mr. W. S. Bisat states (*in litt.*): "I have examined the shale exposures in the R. Churnet near Upper Hulme (S 14 and S 27 of Mr. Challinor) and find that the *R. reticulatum* (Phill.), mut. *bilingue* (Salt.) recorded by Mr. Challinor is the late form of that species."]

[3] Geological Survey Collection, T 90^b, 99^b.

In North-east Staffordshire J. Challinor has recorded *Gastrioceras cancellatum* Bisat and *Reticuloceras reticulatum* (Phillips), mut. *superbilingue* Bisat, from above the Roches Grits near Gib Torr Farm.[1]

Gastrioceras cf. *subcrenatum* (Schlotheim)[2] has been recognized from Biddulph Grange. The occurrence of this form overlying the Rough Rock or First Grit provides a palaeontological correlation of that grit with the Rough Rock of Yorkshire.

Another Lower Coal Measure marine band occurs above the Crabtree Coal. In the Biddulph Coalfield *Gastrioceras listeri* (Martin), *Posidonomya gibsoni* (Brown MS., Salter) and *Pterinopecten papyraceus* (J. Sow.) have been collected from Woodhouse Colliery by Miss E. Dix. From exposures in Consall Wood and Blackbank Brook in the Cheadle Coalfield *Gastrioceras listeri* (Martin), *G.* cf. *coronatum* Foord & Crick, *Posidonomya gibsoni* (Brown MS., Salter), *Pterinopecten papyraceus* (J. Sow.), *Lingula mytiloides* (J. Sow.), *Acanthodes major* Davis, *A. wardi* Egerton and *Elonichthys aitkeni* Traquair have been identified.

Stratigraphical Details

The following notes on the distribution of the Millstone Grit Series of North-east Staffordshire have been compiled mainly from Mr. C. B. Wedd's description of that area.[3]

In the north-west the First Grit or Rough Rock was found by C. B. Wedd to be everywhere persistent except to the south-west of Biddulph, where it dies out. As previously stated, a marine band with *Gastrioceras* cf. *subcrenatum* (Schlotheim) occurs above this grit.

The shales between the First and Third Grits contain the most persistent goniatite horizon in the Millstone Grit, that of *Gastrioceras cancellatum* Bisat.

In North-west Staffordshire the Third Grit is strongly represented, and the Fourth Grit, separated from the grit above by shale, was found by C. B. Wedd to be well represented in the Rudyard area. It is still to be found in Spring Coppice farther to the west, but it fails to appear again either in a southerly or westerly direction. Where it persists, this grit is seen to be separated by shale from the underlying Fifth Grit. Owing to its impersistence, and the lack of continuous sections, it is extremely difficult to trace the relationship of the Fourth Grit to the marine horizons occurring in the adjacent shales. It is very probable that the marine bands with *Reticuloceras reticulatum* (Phill.), mut. *bilingue* (Salter), and *R. reticulatum* (Phill.), mut. *gracile* Bisat, occur above the Fourth Grit, and that the one with *R. reticulatum* (Phill.) occupies a position below this grit.

[1] Challinor, J., *op. cit.*, 1929-1930, p. 42.
[2] Identification confirmed by Mr. W. S. Bisat.
[3] 'Geology of the Country around Macclesfield . . .' (*Mem. Geol. Surv.*), 1906, pp. 31-37.

The Fifth Grit has also been found to diminish in thickness. It is reported to be present on the eastern and western limbs of the Lask Edge anticline, but there is no further indication of it to the west.

Below the Fifth Grit are shales, sandstones, calcareous mudstones, thin earthy limestones and quartzitic sandstones, estimated at about 1,000 ft.,[1] resting on the Carboniferous Limestone. Mr. Wedd's interpretation of the Rushton area places the marine bands exposed in Dingle Brook below the Fifth Grit. These contain, in descending order, *Reticuloceras inconstans* (Phillips) and *Homoceras sp.*, the latter probably representing the *H. proteum* (Brown) and *H. smithi* (Brown) horizon. Only one marine band lower than the last named horizon has been recognized in North-west Staffordshire. This has produced *Anthracoceras paucilobum* (Phillips), which signifies a horizon in the upper part of the Eumorphoceras Zone (E_2). This locality, Hollywood Dingle, is further discussed in the paragraphs dealing with plant-horizons (p. 45).

From the limestone of Astbury, underlying the Millstone Grit, *Prolecanites compressus* (J. Sow.) and *Cyathaxonia sp.* have been recorded,[2] presumably indicating a horizon low in the Beyrichoceras Zone (B). No evidence of the Posidonomya Zone (P) has yet been discovered in this area.

In North-east Staffordshire the horizon of *Gastrioceras cancellatum* (Bisat) has been recorded in a position above the Roches Grits.[3] The statement by J. Challinor that the Roches Grits are approximately the equivalent of the First and Middle Grits must in consequence be modified.[4] Below these beds, within the series called the Churnet Shales, the upper parts of the Reticuloceras and Eumorphoceras Zones (R_2 and E_2) have been previously recorded,[5]

From other localities within the same area there is additional evidence of the Reticuloceras Zone within these shales, marine bands with *Reticuloceras reticulatum* (Phillips), early mut. *bilingue* (Salter), *R. reticulatum* (Phill.), mut. *gracile* Bisat, and *R. inconstans* (Phill.) having been recognized. That the Homoceras Zone is also present is suggested by the occurrence of *Homoceras striolatum* (Phill.), cf. var. *subglobosum* Bisat, from a locality near Leek. Further evidence of the upper part of the Eumorphoceras Zone (E_2) is provided by the marine bands in the River Hamps, and also by goniatites from the Cheddleton Paper Mills Boring. That the lower beds of the Churnet Shales are

[1] 'Geology of the Country around Macclesfield . . .' (*Mem. Geol. Surv.*), 1906, p. 8.
[2] Wheelton Hind, *op. cit.*, p. 574.
[3] Challinor, J., *op. cit.*, 1929-1930, p. 42.
[4] Mr. W. S. Bisat states, *in litt.*: "Mr. Challinor has recorded *Gastrioceras cancellatum* Bisat from above the Roches Grits, S.W. of Gib Torr Farm, so that the Roches Grit is evidently of the same age as the Huddersfield White Rock of Yorkshire. Beneath this there appears to be an absence of Middle or Third Grits, which recalls the similar paucity of sandstones at this horizon recorded by the Geological Survey S. of Glossop (see 'Summary of Progress' for 1927 (*Mem. Geol. Surv.*), 1928, Pt. 1, p. 44). The same fact is evidently true to the east, for 1½ m. S. of Beeley a shale scar on the banks of the River Derwent yields both *Reticuloceras reticulatum* (Phillips), mut. *bilingue* (Salt.), and the later form of that mutation, in separate bands, with no trace of sandstone near those two horizons."
[5] Challinor, J., *op. cit.*, 1928-29, p. 112.

within the lower part of the Eumorphoceras Zone (E_1) is proved by the occurrence of *Eumorphoceras* aff. *pseudobilingue* Bisat near Waterhouses Station.

The Morredge Grits below the Churnet Shales are considered by J. Challinor to be the probable equivalent of the Pendle Grits of Lancashire.[1]

The strata below these grits have received some attention.[2] From the upper beds of limestone and shale *Goniatites sphaerico-striatus* Bisat has been recorded.[3] This specimen has been examined by Mr. Bisat, who has identified it as *Goniatites* cf. *dinckleyensis* Bisat, indicating a horizon low in the Posidonomya Zone (P_1).[4]

The underlying limestone is considered to fall within the upper part of the Dibunophyllum Zone.[5]

From the foregoing evidence, a correlation of the Millstone Grit succession of North-west Staffordshire with that of the north-east suggests itself. The accompanying table illustrates such a correlation, with the goniatite horizons tentatively inserted (Table B).

A correlation of the Churnet Shales with the Sabden Shales of Lancashire has been suggested.[6] As the upper part of the Reticuloceras Zone is represented in the Churnet Shales, that entire series cannot be placed within the Sabden Shales. In North-west Staffordshire the shales and associated beds below the Fourth Grit may be correlated on definite palaeontological evidence with the Sabden Shales.

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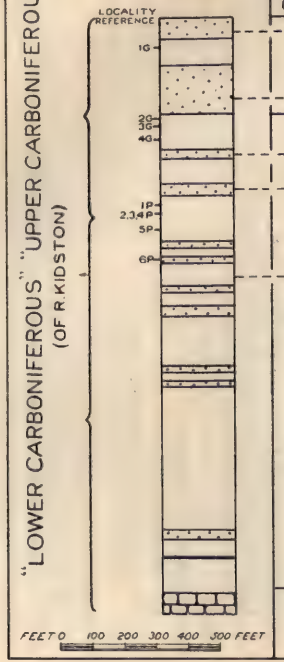
[1] Challinor, J., *op. cit.*, 1928-29, p. 111.
[2] Challinor, J., *op. cit.*, 1927-28, pp. 96-109.
[3] Challinor, J., *op. cit.*, 1927-28, p. 105.
[4] Mr. W. S. Bisat states, *in litt.*: "The specimen obtained by Mr. Challinor from near Mixon, and referred to by him as *Goniatites sphaerico-striatus* Bisat, appears to me to be near *G. dinckleyensis* Bisat, and suggests that the limestones at Mixon Hey Quarry are P_{1a} in age. The shales that succeed the limestones contain *G. granosus* Portlock in a scar at or near the locality S 12 of Mr. Challinor, ¼ mile upstream from Onecote Grange, and are P_2 in age. I have also seen badly preserved goniatites suggestive of a slightly earlier period (late P_{1c}) in shales scars nearer Onecote Grange."
[5] Challinor, J., *op. cit.*, 1927-28, p. 105.
[6] Challinor, J., *op. cit.*, 1928-29, p. 112.

TABLE B.—CORRELATIONS

N. STAFFORDSHIRE SUCCESSION WITH PLANT HORIZONS AS RECORDED BY R KIDSTON (OP CIT., PL A)	N.W. STAFFORDSHIRE	N.E. STAFFORDSHIRE	ZONE
"LOWER CARBONIFEROUS" "UPPER CARBONIFEROUS" (OF R. KIDSTON)	LOWER COAL MEASURES	GOLDSITCH COAL MEASURES	G
	Gastrioceras cf. *subcrenatum* (SCHLOTHEIM)		
	FIRST GRIT (ROUGH ROCK)	*Gastrioceras cancellatum* BISAT ROCHES GRITS	
	THIRD GRIT		
	Reticuloceras reticulatum (PHILL.), MUT. *bilingue* (SALTER)		R
	FOURTH GRIT	*Reticuloceras reticulatum* (PHILL.), MUT. *gracile* BISAT	
	FIFTH GRIT	*Reticuloceras reticulatum* (PHILL.)	
		Reticuloceras inconstans (PHILL.)	
	Homoceras proteum (BROWN), *H. smithi* (BROWN)		H
	Homoceras AFF. *undulatum* (BROWN)		
		Homoceras striolatum (PHILL.), CF. VAR. *subglobosum* BISAT	
		Eumorphoceras bisulcatum GIRTY	
	Anthracoceras paucilobum (PHILL.); THIS IS THE SUGGESTED TRUE POSITION OF KIDSTON'S HORIZON 5P.		E
		Gravenoceras stellarum BISAT	
		Eumorphoceras AFF. *pseudobilingue* BISAT	
		MORREDGE GRITS	
	AGGLOMERATES & TUFFS ON CARBONIFEROUS LIMESTONE	*Goniatites granosus* PORTLOCK CARBONIFEROUS LIMESTONE	P

CHURNET SHALES

Eumorphoceras Homoceras Reticuloceras Gastrioceras



Plant-distribution in the Millstone Grit of North Staffordshire

The section published by R. Kidston, to which reference has previously been made, was used by him to illustrate the distribution of Lower and Upper Carboniferous plants within these rocks. These plants have been revised recently by Miss E. Dix, who has supplied the following list of determinations:—

Zone of Gastrioceras

Cf. Neuropteris schlehani *Stur*
Annularia radiata *Brongn.*

Zone of Reticuloceras

Adiantites *cf.* adiantoides *Lindl. and Hutt.*
Sphenopteris sp.
Diplotmema sp.
Mariopteris sp., ? *cf.* acuta (*Brongn.*)
Neuropteris gigantea *Sternb.*
,, schlehani *Stur*
Lepidophyllum lanceolatum *Lindl. and Hutt.*
Sigillaria elegans *Sternb.*
,, sp.
Calamites *cf.* cistiformis *Stur*
,, undulatus *Sternb.*
,, sp.
Sphenophyllum sp.

Zone of Homoceras

Rhodea feistmanteli *Kidston*

Zone of Eumorphoceras

Adiantites tenuifolius (*Göpp.*)
,, sp.
Alloiopteris quercifolia (*Göpp.*)
Archaeopteridium tschermaki (*Stur*)
Lyginopteris (Calymmatotheca) stangeri (*Gothan*)
Rhodea feistmanteli *Kidston*
,, sp.
Sphenopteris sp.
Cf. Boweria sp.
Neuropteris antecedens *Stur*
,, sp. nov. (related to *N. bohdanowiczi* Zalessky)
Pecopteris aspera *Brongn.*
Cf. Archaeocalamites sp.
Cf. Asterocalamites scrobiculatus (*Schloth.*)
Calamites sp.
Sphenophyllum tenerrimum *Ett.*
,, sp.
Cordaites *cf.* principalis (*Germar*)
Holcospermum ellipsoideum (*Göpp.*)

It has been suggested by Dr. J. W. Jackson that Kidston's section does not represent the true state of affairs.[1] It will now be shown that Kidston was in error in assigning the locality 5P (Hollywood Dingle) to the position he gave it in his stratigraphical sequence.

The position of the plant break was placed in this sequence about 110 ft. below the Fifth Grit, or approximately 350 ft. below the base of the Third Grit (see section on p. 43). This conclusion was based on the undoubted ' Lower Carboniferous ' nature of the flora obtained from Hollywood Dingle (Loc. 5P of Kidston), from shales below a grit considered by G. Barrow to be the Stanley Grit,[2] a grit of local development, which was tentatively correlated with the Fifth Grit.[3] In association with these plants occurs a marine band with *Anthracoceras paucilobum* (Phill.),[4] which indicates a horizon within the upper part of the Eumorphoceras Zone.

The horizon of the *Homoceras proteum* (Brown) and *H. smithi* (Brown) marine band is known definitely to be approximately 500 ft. below the Third Grit. It thus occupies a position 150 ft. below the position assigned by Kidston to the Hollywood Dingle plant-horizon (5P).

As the associated fauna of this plant bed has been proved to belong to the Eumorphoceras Zone, it is here considered that the correlation of the grit above the plant bed with the Fifth Grit was fallacious, and that the plant and marine beds of Hollywood Dingle occupy a horizon well below the *H. proteum* (Brown) and *H. smithi* (Brown) marine band.

A further locality, Limekiln Wood (Loc. 6P of Kidston) was also placed by Kidston within the Lower Carboniferous as interpreted by plant evidence. The plants recorded, *Rhodea sp.*, *Calamites sp.* and *Artisia approximata* (Brongn.) cannot be considered to merit this conclusion. This plant-horizon would appear to be a short distance above the *H. proteum* (Brown) and *H. smithi* (Brown) marine band, but as it has not been possible to trace the exact locality, this cannot be verified.

Rhodea feistmanteli Kidston, a plant which Kidston claimed to be restricted to the ' Lower Carboniferous ' rocks, has been recorded by him from a railway cutting 2 miles south-south-east of Leek.[5] A marine band associated with this plant bed contains *Homoceras striolatum* (Phill.), cf. var. *subglobosum* Bisat,[6] suggesting that plants of ' Lower Carboniferous ' nature extend into the Homoceras Zone.

When making his collection of plants from the Hollywood Dingle section, D. Tait collected several specimens of insect

[1] Jackson, J. W., ' Problems in the Classification of the Carboniferous Rocks,' *Journ Manchester Geol. Assoc.*, vol. i, pt. 2, 1929, p. 74.
[2] ' Geology of the Country around Stoke-upon-Trent ' (*Mem. Geol. Surv.*), 2nd Ed., 1905, p. 3.
[3] *Op. cit.*, p. 9.
[4] Geol. Surv. Coll., T 470[b], 471[b].
[5] Kidston, R., *op. cit.*, p. 235.
[6] Geol. Surv. Coll., JP 2981[a].

wings.[1] These are of special interest as they come from the lowest horizon from which insect wings have been recorded in this country.

Summary and Conclusions

It will be seen from the evidence above reviewed that in terms of the revised Upper Carboniferous succession, the Millstone Grit must in North Staffordshire be extended downwards to include the so-called Pendlesides and Yoredales, that is, to the base of Zone E.

Various goniatite zones are recorded, and most of the shales and associated beds downwards from the Fourth Grit are shown to be equivalent in age to the Edale Shales of Derbyshire and the Sabden Shales of Lancashire.

The Fifth Grit of North Staffordshire has been proved to occur within the lower part of the Reticuloceras Zone (R_1), and the Hollywood Dingle plant-horizon, containing a Lower Carboniferous flora, which Kidston placed a short distance below the Fifth Grit, has been found to be within the upper part of the Eumorphoceras Zone (E_2). The conclusion therefore follows that the Hollywood Dingle horizon occupies a much lower position in the sequence than that hitherto assigned to it.

The occurrence of *Rhodea feistmanteli* Kidston in association with *Homoceras striolatum* (Phill.), cf. var. *subglobosa* Bisat, suggests that the ' Lower Carboniferous ' flora of Kidston extends into the Homoceras Zone, thus confirming the view held by W. S. Bisat[2] that the entry of the ' Upper Carboniferous ' flora probably occurs within that zone.

Acknowledgments

The author is indebted to Mr. W. S. Bisat for assistance in the identification of some of the goniatites and for advice and information given; to Miss E. Dix for the identification of the plants; to Dr. W. D. Lang and Dr. L. F. Spath for access to the Wheelton Hind Collection; and to Dr. Kitchin and Dr. Stubblefield for much helpful advice and criticism.

List of Fossil-localities on the Millstone Grit

The localities are indicated on the sketch-map by means of their numbers.

Specimens in the Geological Survey Collection.

1. Congleton Edge; quarry at Silica Works S.W. of Willocks Wood.
2. Quarry 32 chains N.E. of Puddlebank.
3. Stream on S.E. side of Limekiln Wood, W. of Corda Well.

[1] Geol. Surv. Coll., T 456[b], 621[b]-625[b], 685[b], 686[b].
[2] Bisat, W. S., *op. cit.*, 1924, p. 49.

4. Timbers Brook, E. of millpond.
5. Confluence of two streams ⅛ mile E. of Spring House.
6. Stream 25 yds. downstream from footbridge, ⅛ mile N. of Almshouses of Biddulph Grange.
7. Stream in Crowborough Wood, fully ½ mile N.E. of Warders Towers, Knypersley Reservoir.
8. Dingle Brook, Rushton James; midway between Ashmore Heath and Stony Edge.
9. Dingle Brook, Rushton James; S.W. of Rushton Hall.
10. Dingle Brook, Rushton James; 30 yds. below ford S. of Rushton Hall.
11. Dingle Brook, Rushton James; S. of Fold Farm.
12. Hollywood, 1 mile N. of Endon; stream N.W. of Endon Mill.
13. Shell Brook, N.E. of Hug Bridge; about 120 yds. upstream from its confluence with stream from Nettlebed's Farm.
14. Shell Brook; a little S.E. of Mareknowles.
15. Shell Brook, Greasley Hollow; a few yards above where footpath crosses to Lower Greasley.
16. Shell Brook, Greasley Hollow; about 40 yds. above where stream crosses to Lower Greasley.
17. River Dane; S.S.W. of Hammond's Hole.
18. Dane Valley; 100-150 yds. S. of house at Hammond's Hole.
19. River Dane; left bank upstream from Fall Wood.
20. Stream in Harston Wood, near Harston Rock, N.E. of Froghall.
21. Stream in Consall Wood, nearly ½ mile from junction with River Churnet.
22. Blackbank Brook, opposite Park Mill.
23. Railway cutting 300 yds. N.W. of Blacksmith's Arms, 2 miles S.S.E. of Leek.
24. Railway cutting, nearly ⅛ mile N. of St. Mary's Church, Caldon.
25. Felt House Wood, S.W. of Leek.
26. Cheddleton Paper Mills Borehole, near Leek.
27. Woodhouse Colliery, Biddulph.

Localities of specimens recorded by Mr. W. S. Bisat (in litt.)

28. Railway cutting W. of Waterhouses Station.
29. River Hamps, W. of Waterhouses Station.

Localities of specimens in the Wheelton Hind Collection in the British Museum (Nat. Hist.)

30. Star Wood, Oakamoor.

Not indicated on sketch-map :—
River Dane; near Viaduct.
River Dane; near Bosley.

Localities of specimens recorded by Mr. J. Challinor

31. 750 yds. S.W. of Gib Torr Farm.
S21. River Churnet; 1½ m. E.N.E. of Upper Hulme.
S20. River Churnet; 1¼ m. E. of Upper Hulme.
S16. River Churnet; 1½ m. N.E. of Upper Hulme.
S14, S27. River Churnet; ¼ m. S.E. of Upper Hulme.
S28. River Churnet; 1½ m. S. of Upper Hulme.

Plant-localities of R. Kidston

(Specimens collected by the Geological Survey)

1G. Stream on east side of Knypersley Reservoir, Hollin Wood, where small stream from S.E. joins main stream.
2G. In stream, ⅝ mile E. of Biddulph Grange, at junction of two streams ⅛ mile E. of Spring House.

3G. Shirley Hollow, about ½ mile N.E. of Froghall, in main stream, between two branches which enter on left and on N. side of Caldonlow tramway.

4G. Shale below Third Grit in branch streams in Crowborough Wood, N.E. of Knypersley Reservoir.

1P. Dane Valley, where small stream joins canal feeder, 100-150 yds. S. of house at Hammond's Hole.

2P. Bed of River Dane, at bend of river, S.S.W. of Hammond's Hole.

3P. Shell Brook, branch of River Dane, near Mareknowles, fully ⅛ mile N. of Barleighford.

4P. South bank of canal feeder on south side of River Dane, fully ½ mile E. of Hug Bridge; and River Dane, bed of river, ⅛ mile S. of Bosley railway station.

5P. Hollywood, 1 mile N. of Endon; small exposure on right bank of stream, fully ¼ mile W.N.W. of Endon Mill.

6P. Stream on north side of Limekiln Wood, 2½ miles S. of Congleton Edge.

IV.—NOTES ON THE ORDOVICIAN ROCKS OF BAUSLEY, MONTGOMERYSHIRE

BY

C. B. WEDD, B.A.

Text-figure 1.

A SMALL area of Ordovician rocks, forming a continuation eastwards of the elevated tract[1] of the Breidden Hills, was mapped by the present writer in connexion with the survey of the Shrewsbury Coalfield. Its position is shown in Fig. 1.

The portion of the outcrop here described is less than a square mile in area and extends northward from Braggington Coppice to the Severn. It is almost entirely limited on the east by the Braggington Coppice Fault which brings in the Upper Coal Measures, and is divided diagonally by the Bryn-poeth Fault which separates the visible outcrops of the lower and the upper parts of the sequence. The whole sequence is truncated above by an unconformity, which brings strata of Upper Llandovery age transgressively across a denuded Ordovician series. The general sequence, so far as seen here, may be summarized as follows :—

Bala :—

Caradoc Series.—

Braggington Shales.—Grey and olive-green micaceous shales with silty flags, the whole locally stained dull purple and bright crimson under the influence of the unconformable Ruabon Marl: *Amplexograptus arctus, A. perexcavatus, Climacograptus antiquus, Glyptograptus euglyphus, G. teretiusculus,* var. *siccatus, Hallograptus mucronatus, Orthograptus rugosus,* var. *apiculatus, Orthis* (*Dalmanella*) *sp., Trinucleus concentricus, Tetradella complicata.* (Western part of Braggington Coppice and ground north of it).

(*Gap*)

Limestones and Flags.—Calcareous shales with limestones and (ashy ?) sandstones: *Climacograptus antiquus, Diplograptus multidens, Orthis* (*Dalmanella*) *testudinaria, Cliftonia* [*Triplecia*] *spiriferoides, Strophomena sp., Ampyx* ?, *Primitia sp., Tetradella complicata. Trinucleus concentricus.* (Midway between Braggington Coppice and Bryn-poeth).

Bausley House Shales.—Grey clay shales. (West and south-west of Bausley House).

(*Bryn-poeth Fault*)

Shales with Hill Farm Flags.—Grey shales with group of ashy flags. (Slopes and stream valley south-east of Bausley Hill).

[1] The writer is greatly indebted for the elucidation of this disconnected tract to Prof. W. W. Watts, who in 1921 gave him the benefit of his detailed knowledge of the Breidden Hills and their stratigraphy in the field; to Dr. G. L. Elles for naming most of the graptolites; also to Dr. J. Pringle and especially to Dr. C. J. Stubblefield for much help both in collecting the necessary fossils and in classifying the sequence.

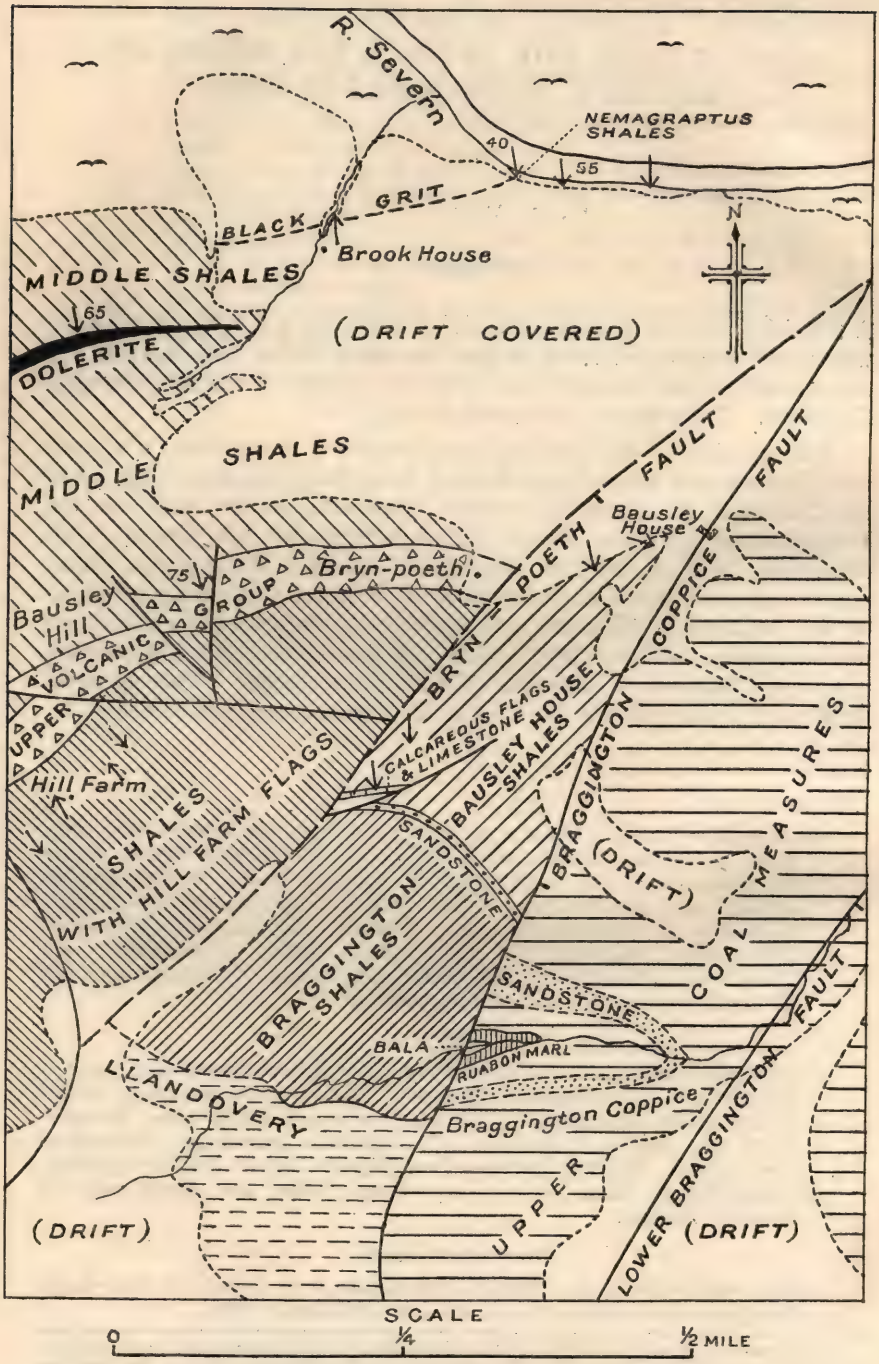


FIG. 1.—*Sketch-map of the district near Bausley.*

Caradoc Series (*contd.*).—
Upper Volcanic Group.—
Hill Farm Ash :—stratified ash—*Amplexograptus perexcavatus, Climacograptus antiquus, Orthograptus rugosus,* var. *apiculatus, Baliactis ordovicus, Orthis* (*Dalmanella*) *sp., Trinucleus sp., Tetradella complicata.* (Lane west and south-west of The Hill Farm).
Andesite Conglomerate : conglomerate of rounded andesite pebbles or small boulders. (Bausley Hill).
' Cottage Ash.'
Andesite Conglomerate : conglomerate of rounded andesite pebbles or boulders. (Bausley Hill).
China-stone Ash : with large kaolinized felspars locally. (Bausley Hill).
Middle Shales above dolerite.—Grey shales so far as seen : upper beds just below ash contain *Climacograptus antiquus* ?, *C. scharenbergi* ?, *Diplograptus multidens, Trinucleus concentricus* ?, (Quarry on north side of Bausley Hill). Lowest beds, baked at bottom just above the dolerite, contain *Climacograptus brevis, C. scharenbergi, Dicellograptus divaricatus,* var. *salopiensis, Lasiograptus harknessi,* var. *costatus, Leptograptus* ?, *Diplograptus multidens.* (Brook in Brimford Wood, S.E. of Brimford House).
Breidden Dolerite (intrusive).
Middle shales below dolerite.—Highest beds dark shales baked just below dolerite : lowest beds, grey shales with occasional flags, contain *Amplexograptus arctus, A. perexcavatus, Climacograptus antiquus, C. brevis, Cryptograptus tricornis,* var. *schäferi, Lasiograptus harknessi,* var. *costatus, L. retusus, Diplograptus* cf. *foliaceus,* D. *multidens, Orthograptus rugosus,* var. *apiculatus,* Eurypterid. The lowest 4 ft. of shale yielded *Nemagraptus* ?. (South bank of Severn east of Brook House dingle, in which shales containing *Amplexograptus arctus* appear to belong to the same group, above the ' Black Grit ').
Lower Volcanic Group (' White Ashes ').—Hard splintery cherty ash in bands, with associated shales in lower part. (South bank of Severn west of the above shales).
Black Grit.—Hard flaggy and fissile fine-grained black sandstone. (South bank of Severn, west of ' White Ashes ').
Nemagraptus Shale.—Dark grey shales : *Amplexograptus arctus, Lasiograptus retusus, Nemagraptus sp., Orthograptus rugosus,* var. *apiculatus.* (South bank of Severn, west end of section).

The eastward limitation of the whole Lower Palaeozoic outcrop by the Braggington Coppice Fault is complete, except that in the Braggington Coppice dingle the stream has cut down through the few feet of crimson Ruabon Marl underlying the Coed-yr-allt Beds of the Upper Coal Measures on the east side of the fault and has exposed, in a faulted ' window,' weathered Bala shales stained the same colour but tougher than the Ruabon Marl and slightly micaceous.[1]

Of the above sequence Professor Watts[2] first correlated the Upper Volcanic Group with ' the top of the Glenkiln or bottom of the Hartfell series ' but later[3] he correlates the upper part of the sequence down to the top of the Upper Volcanic Group with the

[1] A section in the south bank of the stream was cleared in 1921 by Messrs. Templeman and Hester, who obtained *Trinucleus concentricus* from the stained shales on the east side of the fault, beneath a few feet of Ruabon Marl, which dips eastward beneath the base of the overlying Coed-yr-allt Beds. Prof. Watts had long known of the existence here of a fault throwing red Coal Measures against stained shales of Bala age.

[2] ' On the Igneous and Associated Rocks of the Breidden Hills . . . ' *Quart. Journ. Geol. Soc.*, vol. xli, 1885, p. 534.

[3] ' The Geology of South Shropshire,' *Proc. Geol. Assoc.*, vol. xxxvi, 1925, p. 340.

EX BIBL. UNIV. EDINBURGEN.

Whittery Shales of the Chirbury Series in the Shelve country and with the Acton Stage of the Caradoc country, in which he regards the Acton Calcareous Beds as containing a representative of the Breidden Limestone and Flag Group and the Upper Trinucleus Shales as equivalent to the Braggington Shales above that group. He further states[1] that 'at the Breidden Hills, on the county boundary, only Caradocian strata, with volcanic rocks, are known,' but also records[2] Dr. A. Wade's opinion that the Trinucleus Shales of the Caradoc country should be placed in the Ashgillian.

The Upper Volcanic Group and the underlying Middle Shales of the Breidden tract down to the top of the White Ash Group are correlated by Professor Watts respectively with the Whittery Ash and the Hagley Shales of Shelve and with the Longville Stage of Caradoc; the lowest shales of the Breidden tract below these ashes with the Harnage Stage of Caradoc and the Aldress Stage of Shelve.[3]

It seems desirable to institute here a comparison, if possible, with the Ordovician sequence of the Oswestry and Wrexham districts. But changes of lithological character and physical conditions with consequent changes of faunal type between these districts so far preclude all certainty of detailed correlation.

In the Breidden sequence the graptolite *Diplograptus multidens* Elles and Wood has been found to range from a horizon a few feet above the 'White Ashes' (Lower Volcanic Group) upward into the Limestone and Flag Group. In Dr. Stubblefield's opinion all these strata and also the higher shales up to the unconformity that brings in the Llandovery beds, should, on account of their faunal assemblage, be assigned to the Caradoc zone of *Diplograptus* [*Mesograptus*] *multidens*, while the beds below the Black Grit may belong to that of *Nemagraptus gracilis*.[4] In any case the beds next below those containing *Diplograptus multidens* must presumably be close to the base of the Caradoc Series, so that the underlying White Ashes may conceivably lie on the horizon of the Cwmclwyd Ash of the Oswestry district (Sheet 137),[5] where, however, none of the sandstones in the highest part of the Llandeilo Series resembles the remarkable Black Grit below the White Ashes. The presence of several ash-beds in the upper part of and above the Teirw Group of the adjacent district[6] suggests continuity of some of these products of volcanic activity between the two districts, while the higher Limestone and Flag Group of the Breidden tract invites comparison with the Pen-y-garnedd Limestone in the southern part of the Oswestry district, where that Limestone lies perhaps at a less distance above the base of the Caradoc Series.

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[1] *Op. cit.*, p. 339.
[2] *Op. cit.*, p. 345: see also table on p. 340, where the corresponding beds of this district as well as those of the Acton Stage and the Whittery Shales are assigned to the Ashgillian.
[3] *Op. cit.*, p. 340.
[4] These conclusions have been confirmed by Dr. G. L. Elles.
[5] 'The Country around Oswestry' (*Mem. Geol. Surv.*), 1929, pp. 3, 45, 47.
[6] *Op. cit.*, p. 3.

The Blaen-y-cwm Beds of the southern part of the Wrexham and the northern part of the Oswestry district, where they represent the Pen-y-garnedd Beds as the highest member of the Caradocian in the southern part of the latter district, contain several graptolites, of more or less restricted vertical range, in common with the Breidden tract. *Climacograptus antiquus, C. brevis, C. scharenbergi, Glyptograptus euglyphus,* and *Diplograptus multidens,* the last two, it appears, of more general occurrence than the others,[1] are all recorded from the Blaen-y-cwm Beds, as well as a form comparable with *Cryptograptus tricornis,* var. *schäferi* and doubtfully *Amplexograptus.* This graptolite assemblage is characteristic of the Breidden sequence from the highest Ordovician strata there represented down to the White Ashes in the bank of the Severn, except that *Climacograptus brevis, C. scharenbergi* and *Diplograptus multidens* have not been found above the Limestone and Flag Group. Of these graptolites *Amplexograptus perexcavatus, Climacograptus brevis, C. scharenbergi* and *Glyptograptus euglyphus* occur also in the Pen-y-garnedd Shales, the higher member of the Pen-y-garnedd Beds. Moreover, the brachiopod *Cliftonia* [*Triplecia*] *spiriferoides,* which is said to be characteristic of the lower part of the Pen-y-garnedd Limestone,[2] is found in the Limestone and Flag Group of this district, as well as in the Bryn Beds of the Oswestry and Wrexham districts.

While a comparison of the sequence here and in the district to the north-west suggests a reasonable correspondence of the white rhyolitic ashes in the bank of the Severn near the bottom of the Breidden sequence with the Cwmclwyd Ash, and of the Limestone and Flag Group with the lower part of the Pen-y-garnedd Limestone, the latter suggestion is not justified by present knowledge of the zonal range of graptolites. By Dr. Stubblefield's showing on that evidence, the whole Breidden sequence, from a few feet above the White Ashes up to the unconformity that brings in the Upper Llandovery, belongs to the zone of *Mesograptus multidens.* On the same evidence it is now suggested by him that this sequence is represented by the whole group of the Blaen-y-cwm Beds, and further that they themselves are in turn represented by only the middle part of the Pen-y-garnedd Shales, which, while only some 50 ft. thick, from the evidence of the graptolites recorded[3] would appear to range upward into the zone of *Pleurograptus linearis* and down into the *Nemagraptus* Beds, although no zonal subdivision of these shales was considered feasible by the writers of the Oswestry memoir.

As already stated, the Ordovician strata of this tract had been denuded before the deposition of the unconformable Upper Llandovery, and there is no evidence of the presence of any beds of Ashgillian age. The highest Ordovician strata represented

[1] Smith, B., and L. J. Wills, in 'The Country around Wrexham,' Part I (*Mem. Geol. Surv.*), 1927, p. 36.
[2] Smith, B., and W. B. R. King, in 'The Country around Oswestry' (*Mem. Geol. Surv.*), 1929, p. 53.
[3] Smith, B., in 'The Country around Oswestry' (*Mem. Geol. Surv.*), 1929, pp. 45, 51-56.

must be those of the ' window ' beneath the Ruabon Marl in the valley of the Braggington brook east of the Braggington Coppice Fault. In the stained Ordovician strata there exposed only *Trinucleus concentricus* was found, a trilobite of less common occurrence in Ashgillian than in Caradocian beds.

At the extreme west end of the stream section of Caradoc strata in Braggington Coppice, olive grey platy shales crop out with south-westward dip divergent from that of the adjacent Caradoc shales, and have yielded a fauna of Upper Llandovery age. Professor Watts had suggested that the outcrop of these Llandovery beds in its upward transgression eastward across the Caradoc might be expected to pass just above the Braggington shales of the brook section in Braggington Coppice. The soil of the field above the south bank of the brook contains numerous pellets of a brown sandstone of a common Llandovery type: and in 1929 Dr. Stubblefield, in searching for further evidence of a Llandovery outcrop, obtained the following Llandovery assemblage from the transgression shales at the west end of the brook section :— Crinoid columnals, Polyzoa, *Atrypa reticularis* (Linn.), *Leptelloidea scissa* (Dav.), *Pholidops implicata* (J. de C. Sow.), *Schuchertella sp., Sowerbyella sp., Stricklandinia* cf. *lirata* (J. de C. Sow.); *S.* cf. *lirata* [long ' uneared ' var.], cf. *S. lirata* [short var.], [1] *Stricklandinia sp., Homalonotus sp.*

[1] Wills, L. J., and others, ' New Exposures in the Rubery-Longbridge-Rednall District, South of Birmingham,' *Proc. Birmingham Nat. Hist. Soc.*, vol. xv, pt. iii, pp. 71-3.

	Blaen-y-cwm Beds (top of Caradoc)	Pen-y-garnedd Shales (top of Caradoc)	Pen-y-garnedd Limestone	BREIDDENS: Shales above limestones	BREIDDENS: Limestone Group	BREIDDENS: Shales above Ash group	BREIDDENS: Ash group	BREIDDENS: Shales above dolerite	BREIDDENS: Beds below dolerite	BREIDDENS: Lowest beds in river (? Zone of *Nemagraptus gracilis*)	Allt-tair-ffynnon Beds	Bryn Beds	Teirw Beds
Amplexograptus arctus *Elles and Wood*	.	.	.	×	.	.	.	.	×	×	.	.	.
A. perexcavatus (*Lapworth*)	?	×	.	×	.	.	×	.	×	.	.	.	.
Climacograptus antiquus *Lapworth*	×	.	.	×	×	.	×	.	×	.	.	.	.
C. brevis *Elles and Wood*	×	×	.	.	.	.	.	×	×	.	.	.	.
C. scharenbergi *Lapworth*	×	×	.	.	.	.	?	×	.	.	.	.	.
Cryptograptus tricornis, *var.* schäferi *Lapworth*	cf.	.	.	.	.	.	.	.	×	.	.	.	var.
Dicellograptus divaricatus, *var.* salopiensis *Elles and Wood*	.	.	.	.	.	.	.	×	.	.	.	.	.
Dicellograptus ?	?	.	.	.	.	.	.	?	.	.	.	.	.
Diplograptus *cf.* foliaceus (*Murchison*)	.	.	.	.	.	.	.	.	×	.	.	.	.
D. multidens *Elles and Wood*	×	.	.	.	×	.	×	×	×	.	.	.	.
Glyptograptus euglyphus *Lapworth*	×	×	.	×	.	.	.	.	.	.	.	.	.
G. teretiusculus, *var.* siccatus *Elles and Wood*	.	cf.	.	×	.	.	.	.	.	.	.	.	cf.
Hallograptus mucronatus (*Hall*)	.	.	.	×	.	.	.	.	.	.	.	.	.
Lasiograptus harknessi, *var.* costatus *Lapworth*	.	.	.	.	.	.	.	×	×	.	.	.	.
L. retusus *Lapworth*	.	.	.	.	.	.	.	.	×	×	.	.	.
Leptograptus ?	.	.	.	.	.	.	.	?	.	.	.	.	.
Nemagraptus sp.	.	?	.	.	.	.	.	.	?	×	.	.	.
Orthograptus rugosus, *var.* apiculatus *Elles and Wood*	.	.	.	×	.	.	×	.	×	×	.	.	.
Crinoid columnals	.	.	×	.	.	.	×	.	.	.	×	×	.
Baliactis ordovicus *W. K. Spencer*	.	.	.	.	.	.	×	.	.	.	.	.	.
Polyzoa	.	.	.	.	.	.	×	.	.	.	.	.	.
Obolella ?	.	.	.	.	.	.	.	.	.	?	.	.	.
Lingula sp.	.	.	.	.	×	.	.	.	.	.	.	.	.
Orthis (Dalmanella) testudinaria	.	.	.	.	×	.	.	.	.	.	.	var.	var.
Orthis (Dalmanella) *cf.* elegantula	.	.	.	.	.	.	×	.	.	.	var.	cf.	.
O. (D.) sp.	.	?	.	?	?	.	?	.	.	.	.	.	.
O. (Plectorthis) sp.	.	.	?	.	.	.	×	.	.	.	.	.	.
Strophomena sp.	.	.	.	.	?	.	.	.	.	.	.	?	?
Cliftonia spiriferoides (*M'Coy*)	.	.	×	.	×	.	.	.	.	.	.	×	.
Ctenodonta sp.	.	.	.	.	?	.	.	.	.	.	.	.	.
Bellerophon sp.	.	.	.	?	?	.	.	.	.	.	?	.	.
Sowerbyella sp.	.	.	.	.	.	.	×	.	.	.	.	.	.
Ampyx ?	.	.	.	.	?	.	.	.	.	.	.	.	.
Primitia sp.	.	.	.	.	×	.	.	.	.	.	.	.	.
Tetradella complicata (*Salter*)	.	×	.	×	×	.	×	.	.	.	×	×	×
Trinucleus concentricus	.	.	.	×	×	.	?	.	.	.	×	×	var.
T. sp.	.	?	.	×	?	.	?	.	.	.	?	.	?
Cf. Stylonurus (Drepanopterus) type[1]	.	.	.	.	.	.	.	.	×	.	.	.	.

[1] See C. J. Stubblefield, *in* F. L. Kitchin, 'Summary of Progress' for 1929 (*Mem. Geol. Surv.*), 1930, p. 88.

V.—THE MAJOR SUBDIVISIONS OF THE COAL MEASURES IN YORKSHIRE

BY

D. A. Wray, Ph.D., M.Sc.

Text-figure 1.

Introduction

THE Coal Measures of Yorkshire consist of an alternating series of shales and sandstones with beds of coal, fireclay and ironstone, and attain a thickness of over five thousand feet. They constitute an unbroken succession and were originally divided by Phillips into an Upper, Middle and Lower Series. The Middle group included the majority of the workable coal seams and its base was taken at the top of the Elland Flagstones; while the Woolley Edge Rock, a prominent bed of gritty sandstone in the Barnsley district, constituted the upper limit of this series.[1] When, however, the officers of the Geological Survey undertook a systematic survey of the coalfield some twenty years later, they found the Silkstone or Blocking Coal a more suitable datum-line as the base of the Middle Coal Measures, and consequently adopted it both on the official maps and in the accompanying memoirs. This procedure has been very generally followed in subsequent accounts of these measures.

The delimitation of an upper group from the Middle Coal Measures was however a more difficult problem, owing to the absence of any distinctive horizons. The late A. H. Green showed conclusively that the Woolley Edge Rock was a thick wedge of gritstone which thinned away rapidly in a northern, southern and easterly direction,[2] and was therefore a very unsatisfactory datum-line.

In an endeavour to bring the classification of the Yorkshire Coal Measures into line with that adopted in adjacent coalfields, Green himself doubtfully assigned only ' the Red Beds with Coal Plants of Conisborough Pottery ' to the Upper Coal Measures.[3]

The basis of the above classification was largely an arbitrary one, for the fauna and the flora of the Coal Measures were then very imperfectly known. The general character of the measures themselves however does not readily lend itself to such a refined zonal scheme as can be adopted in thick fossiliferous marine formations. Marine horizons, though of the highest value as index horizons, are relatively infrequent in these strata, and it is therefore necessary to employ other criteria in addition.

[1] Phillips, J., ' Manual of Geology,' *London*, 1855, pp. 182-187.
[2] Green, A. H., ' The Geology of the Yorkshire Coalfield ' (*Mem. Geol. Surv.*), 1878, p. 432 and Fig. 35.
[3] Green, A. H., *op. cit.*, pp. 75 and 84.

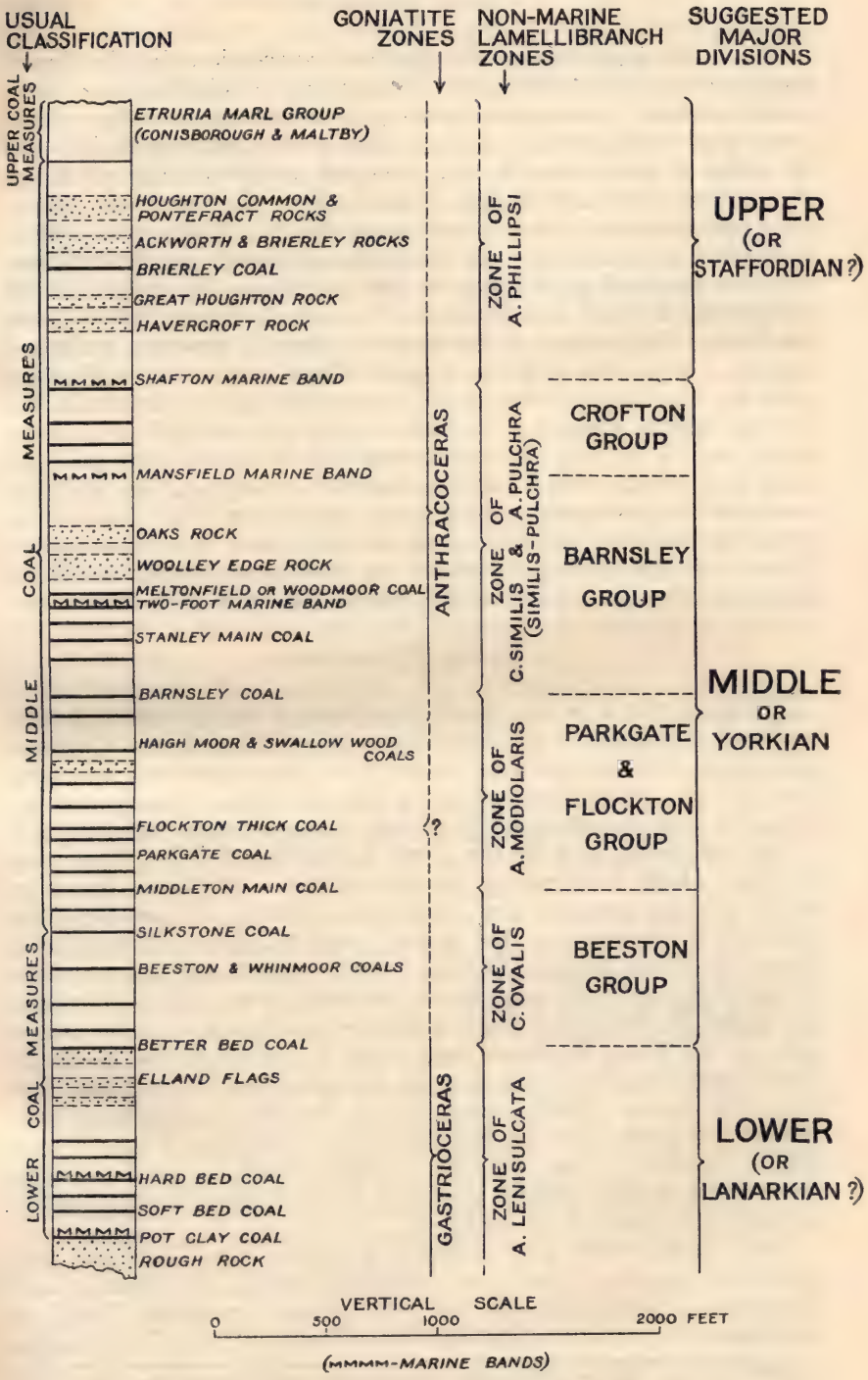

FIG. 1.—*The major subdivisions of the Coal Measures in Yorkshire.*

Index Horizons

To a limited extent the general succession in the lower portion of the Coal Measures is sufficiently distinctive over wide areas to allow close comparisons to be instituted, and the present writer has endeavoured to show that a detailed correlation can be made of the whole of the measures below the Elland Flags throughout the North Midland coalfields.[1] In these rocks practically each individual bed of sandstone, coal, or fireclay, as well as the marine horizons and even the molluscan bands can be identified in a corresponding position in the succession in each coalfield around the Central and Southern Pennines. Immediately above the Elland Flags and their equivalents there is, however, a marked change. It is clear that the large Midland area of deposition had split up into isolated basins only connected at rare intervals, for in these higher measures the beds exhibit very rapid lateral variations, and it is only the occasional marine bands and possibly some coal seams which can be identified throughout the Midland coalfields. Correlation by general characters therefore is no longer practicable, and the most reliable basis for a comparison is furnished by the succession of the freshwater faunas, the flora, and to a very limited extent the marine faunas in each area.

Marine Horizons

There are at least ten distinct horizons at which marine fossils are known to occur in the Coal Measures of Yorkshire. Of these only four yield goniatites; the fauna of the remainder is a very meagre one, consisting only of a few small brachiopods such as *Lingula*, and is consequently of little value for zonal purposes.

In the lower part of the Coal Measures, the Pot Clay and Halifax Hard Bed marine bands contain a goniatite fauna in which *Gastrioceras* is the dominant genus. *G. subcrenatum* (Schloth.) characterizes the lower, and *G. listeri* (Martin) the upper of these bands; though closely allied and intermediate forms occur on both horizons in several areas. The Mansfield (or Monk Bretton) and Shafton marine bands occur in the upper part of the Coal Measures and yield a varied fauna in which Pleuronautilids and Goniatites are the most distinctive forms. In these two bands *Anthracoceras* is the dominant goniatite genus, though the material hitherto obtained in Yorkshire is usually too poorly preserved for specific determination. *Anthracoceras hindi* Bisat would appear, however, to be a characteristic species in the lower band of the two.

Mr. Bisat, who has recently described the Goniatite and Nautiloid fauna of the Coal Measures, refers the Shafton and Mansfield marine bands to the major goniatite zone of *Anthracoceras*, and the Halifax Hard Bed and Pot Clay marine

[1] Wray, D. A., 'The Carboniferous Succession in the Central Pennine Area,' *Proc. Yorks. Geol. Soc.*, vol. xxi, 1929, pp. 228-287.

bands to that of *Gastrioceras*; the latter zone including all the Lower Coal Measures and the upper part of the Millstone Grits. The dividing line between these two zones is taken at the horizon of the 7 Foot Banbury Marine Band of North Staffordshire, the lowest marine horizon with a cephalopod fauna of Pleuronautilids and *Anthracoceras*.[1] This bed has not hitherto been recognized in Yorkshire, though its equivalent may possibly be a band of marine shale with *Lingula*, which has been found about two hundred feet above the Parkgate Coal in some deep borings in East Yorkshire. Over a thousand feet of measures, however, with no marine horizon occur between the 7 Foot Banbury and the Crabtree Coal (the equivalent of the Halifax Hard Bed seam of Yorkshire), so that the line of demarcation between the goniatite zones is an extremely vague one.

Non-marine Faunas

Recent studies on the sequence of the non-marine lamellibranch faunas have been extended to the majority of the British coalfields, mainly under the stimulating guidance of Professor A. E. Trueman, and have shown that several distinct zones can be recognized and used as a basis for the classification and correlation of the Coal Measures.

In Yorkshire five well-marked zones have been established, and their limits are fairly clearly defined.[2] The lowest zone characterized by *Anthracomya lenisulcata* Tr. extends to the top of the Elland Flagstones. The succeeding zone of *Carbonicola ovalis* extending to the Middleton Main or New Hards Coal includes many large species of *Carbonicola* such as *C. ovalis* (Martin), *C. communis* D. and Tr. and related forms not found in the underlying zone. *Carbonicola* bands become very frequent in the succeeding zone of *Anthracomya modiolaris* and that of *Carbonicola similis* and *Anthracomya pulchra* (briefly designated the *Similis-pulchra* zone). Each of these zones has a distinctive fauna (full details of which are given in the paper quoted above), and the line of subdivision between the two is at the horizon of the Barnsley Coal or its equivalents, one of the most readily recognizable and persistent horizons throughout the coalfield.

To the highest zone of *Anthracomya phillipsi* are referred the whole series of measures above the Shafton Marine Band. The base of this zone marks an important palaeontological break; for the genus *Carbonicola* is apparently unrepresented in the measures above it while the only non-marine shells are forms related to the group of *Anthracomya phillipsi*.

[1] Bisat, W. S., 'On the Goniatite and Nautiloid Fauna of the Middle Coal Measures of England and Wales,' 'Summary of Progress' for 1929, Part iii (*Mem. Geol. Surv.*), 1930, pp. 75-89.

[2] Wray, D. A., and A. E. Trueman, 'The Non-marine Lamellibranchs of the Upper Carboniferous of Yorkshire and their Zonal Sequence,' 'Summary of Progress' for 1930, Part iii (*Mem. Geol. Surv.*), 1931, pp. 70-92.

The zone of *Anthracomya tenuis*, which includes the highest Coal Measures in Lancashire and South Wales, is not recognizable in Yorkshire, unless it is represented in the Conisborough district, where Dr. G. H. Mitchell has obtained some vague and poorly preserved Anthracomyas of doubtful affinities.

The Flora of the Coal Measures

It has long been recognized that the Coal Measures contain an extremely rich and varied flora. The relative infrequency of marine horizons, their comparatively meagre fauna and the belief that the non-marine lamellibranchs showed too slight evolutionary changes to be of value for zonal purposes, led to the anticipation that the floral succession would eventually furnish more reliable data for a scientific classification. This expectation has, as yet, hardly been realized. Fossil plants are almost invariably in a fragmentary state; and to isolated fern-like fronds, stems, cones, spore-cases and rootlets a generic and specific nomenclature has been applied. Yet although the foliage constitutes the bulk of the species so named, many of the isolated fronds cannot be referred with certainty to the specific plant to which they originally belonged. The nomenclature is in fact almost exclusively based on the character of the nervation and form of the leaves. The employment of plant-remains as zonal indices is further complicated by ecological considerations. Thus Stopes and Watson have clearly shown that the flora of the roof shales may differ considerably from that of the underlying coal seam.[1] It is also probable that the isolated plant-remains in a large number of cases are not strictly indigenous in the shales and sandstones in which they are found.

A detailed study of the flora of the successive layers in a coal seam has been made by Lomax in Lancashire, while in South Wales D. Davies has prepared an exhaustive statistical record of the plants occurring in the shales overlying ten distinct coal seams. The former has shown that in a coal seam there are successive associations of plant forms of varying habitat,[2] while Davies's results indicate that although the flora may exhibit great similarity over a considerable area at the same horizon, there may be equally great dissimilarity over comparatively small vertical distances, as in the roof-shales of successive coal seams.[3] It is obvious therefore that a truly scientific classification of the Coal Measures is hardly practicable by means of the flora alone until the floras of successive seams in a coalfield have been closely examined.

Another factor which undoubtedly vitiates the employment of floral data for the purposes of zoning is that many species may be

[1] Stopes, M. C., and D. M. S. Watson, 'On the present distribution and origin of the calcareous concretions in coal seams known as Coal Balls,' *Phil. Trans. Roy. Soc.*, Ser. B, vol. cc, 1908, pp. 204-210.

[2] Lomax, J., in *Trans. Inst. Min. Eng.*, vol. l, 1916, pp. 127 & 137.

[3] Davies, D., in *Quart. Journ. Geol. Soc.*, vol. lxxvii, 1921, p. 71.

recorded from a very limited area where exceptional conditions have prevailed during the deposition of the plant-bearing beds. Thus in the Yorkshire Coalfield, by far the largest proportion of plants in the Yorkian (or Westphalian) Series are recorded from the roof of the Barnsley Coal, and a large proportion of these came from the Monckton Main Collieries near Barnsley. This has indeed proved a rich collecting ground, though the rock from which many of the plant-remains were obtained indicates somewhat exceptional ecological conditions in this particular case. The Barnsley Coal is a thick seam which splits as traced northwards through the Monckton Main workings, the upper and lower portions of the seam being in places as much as thirty feet apart. Between the two there comes a fine-grained fissile sandstone termed the ' Monckton Rock,' and it is this bed which has yielded many of the rarer plant species recorded from this locality.

The majority of the published lists, hitherto employed as a basis of classification, also give little or no indicaton of the relative abundance of certain forms on particular horizons. Yet occasional species are frequently dominant and especially characteristic of certain horizons, and in such cases may be of great value in correlating certain seams over limited areas. Thus the roof shales of the Old Hards Coal in the country to the west of Wakefield are characterized by the abundance of a single distinctive form of *Sigillaria*; while in the shales above the Shafton Seam in the Barnsley district *Mariopteris sauveri* (Brongn.) is a characteristic form, practically confined to that horizon. With more intensive collecting this method of correlation could doubtless be considerably extended.

The rapid progress in the microscopic study of thin sections of coal seams has furnished other palaeobotanical data which can be employed for the correlation and identification of particular coal seams. A readily recognizable feature of banded coal is the presence of outer coats or exines of spores, more particularly in the dull bands which are often very persistent. In America, Theissen and others have shown that the form and ornamentation of the spore exines are sufficiently characteristic to be employed as a means of the identification of a particular seam,[1] while Lange has also shown that certain coals in Upper Silesia may be identified and correlated by their differing spore content.[2] This work has been applied in Britain to some of the principal seams in the North Midland coalfields by Slater and others, and appears to be possible of wide application.[3] The spore exines can be referred to a number of distinct types, and a striking feature is the apparently gradual increase in the number of these in the coals of

[1] Theissen, R., and A. W. Voorhees, ' A microscopic study of the Freeport Bed,' *Carnegie Institute of Technology*, Bulletin 2, 1922. (Several other similar bulletins have been published since).

[2] Lange, T., ' Die Bedeutung der Sporen für die Stratigraphie des Karbons,' *Zeit.d.Oberschl. Berg-u.-Hüttenw.*, 1927, 6, p. 340.

[3] Wray, D. A., L. Slater and G. E. Eddy, ' The Correlation of the Arley Mine of Lancashire with the Better Bed Coal of Yorkshire,' ' Summary of Progress ' for 1930, Part ii (*Mem. Geol. Surv.*), 1931, pp. 1-17, and references quoted.

the higher measures. In the Halifax Hard Bed Coal of Yorkshire or the Bullion Mine of Lancashire one main type largely predominates. In the Arley Mine or Better Bed Coal there are four or five main types; while in the Parkgate and Barnsley seams, still higher in the sequence, there is a corresponding increase in the number of main types.

The Major Floral Subdivisions in the Coal Measures

The late R. Kidston, who made an extensive study of the Upper Carboniferous flora, maintained that 'plants give the surest test of age' in the Upper Carboniferous, and established a broad classification which has been very generally adopted, though much further research is required to ascertain whether his boundary lines can be precisely fixed. Kidston's classification is based almost entirely on the proportion of distinctive 'leaf form' species in each group.

A fourfold subdivision was proposed. Three of the divisions correspond broadly with the Upper, Middle and Lower Coal Measures as generally understood, while the fourth, which he named the 'Transition Series' or Staffordian, is a group 'which forms a distinct botanical province, easily separated by the mixed association of species' from the Upper Coal Measures above, and the main mass of Middle Coal Measures below them.[1] The highest subdivision of Kidston's classification, which he termed the 'Radstockian,' is unrepresented in Yorkshire.

The Yorkshire succession therefore falls into three main divisions, viz. (1) the Lanarkian, including the Millstone Grit and Lower Coal Measures; (2) the Westphalian (more recently designated Yorkian by Watts, Crookall and others to avoid confusion with the nomenclature employed by many Continental geologists), including the Middle Coal Measures; and (3) the Staffordian including, in Yorkshire, the upper part of the Coal Measures.

The distinctive characters of these three main groups have been given by Kidston,[2] and need not therefore be further elaborated here. As, however, the suggested boundary lines have resulted in some conflicting views a fuller statement is necessary.

The Boundary between the Lanarkian and Westphalian (or Yorkian)

In his first account of the Yorkshire Carboniferous flora, Kidston followed the original classification of the Yorkshire geologists, and adopted the top of the Elland Flagstones as the

[1] Kidston, R., 'On the Divisions and Correlation of the Upper Portion of the Coal Measures,' *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, p. 319.

[2] Kidston, R., 'On the Various Divisions of British Carboniferous Rocks as determined by their Fossil Flora,' *Proc. Roy. Phys. Soc. Edin.*, vol. xii, 1894, p. 183: also *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, p. 308.

line of demarcation between the Lower and Middle Coal Measures.[1] He further added that although the Geological Survey had adopted the Silkstone Coal, which is a much higher horizon, as the main line of subdivision, palaeontological evidence did not favour such a change. It is remarkable therefore to find that Kidston departed from this earlier procedure in all his later publications and tacitly adopted the higher horizon; and the more so as no reason was ever advanced for such a change. We can only presume he considered the plant evidence insufficiently convincing to outweigh stratigraphical and other considerations.

The same difficulty confronted the late E. A. N. Arber in his accounts of the flora of the southern portion of the coalfield in Derbyshire. In 1910 Arber adopted the Kilburn Coal (the local equivalent of the Better Bed Coal of West Yorkshire) as the line of subdivision between the Lower and Middle Coal Measures,[2] while in a subsequent paper ten years later he followed the Geological Survey and Kidston in preferring the Silkstone or Black Shale Coal as a major floral boundary.[3]

In the Lancashire Coalfield the boundary between the Lower and Middle Coal Measures has always been taken at the level of the Arley Mine Coal, and this horizon was also adopted by Kidston as the boundary between the Lanarkian and Westphalian (or Yorkian) Series. It has since been shown that the Arley Mine seam is almost certainly represented along the Eastern Pennines by the Better Bed Coal of Yorkshire and the Kilburn Seam of Derbyshire.[4] If therefore, as seems eminently desirable, a common line of subdivision is adopted throughout adjacent coalfields, the Better Bed and Kilburn seams would appear to be a more suitable datum-line than that of the Silkstone Coal and its equivalents. The present writer pointed out in 1929 that such a boundary was not inconsistent with the evidence of the fossil plants; thus of the fifty-five species recorded from the measures between the Better Bed and Silkstone coals in Yorkshire, no less than twenty-six are practically confined to and characteristic of the Westphalian Series.[5] The evidence is admittedly incomplete and further collecting is desirable; though as we have already indicated, it is clear from a study of the non-marine Mollusca that the top of the Elland Flags in Yorkshire marks an important palaeontological break, while none exists in the molluscan succession at the horizon of the Silkstone Coal. In addition, we have also pointed out that it is on the former horizon that the most marked change occurs in the general succession of the measures in the North Midland coalfields.

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[1] Kidston, R., 'The Yorkshire Carboniferous Flora,' *Trans. Yorks. Nat. Union*, Leeds, 1890, Part xiv, p. 5.

[2] Arber, E. A. N., 'On the Fossil Flora of the Southern Portion of the Yorkshire Coalfield,' *Proc. Yorks. Geol. Soc.*, vol. xvii, 1910, p. 141.

[3] Arber, E. A. N., 'On the Fossil Flora of the Southern Portion of the Yorkshire Coalfield,' *Proc. Yorks. Geol. Soc.*, vol. xix, 1920, p. 350.

[4] Wray, D. A., 'The Carboniferous Succession in the Central Pennine Area,' *Proc. Yorks. Geol. Soc.*, vol. xx, 1929, pp. 272-285.

[5] *Ibid.*, p. 283.

This question has recently been discussed by Dr. Crookall in a critical revision of Kidston's Coal Measure floras. He proposes to revert to the latest classification adopted by Kidston and the Geological Survey in taking the Silkstone Coal as the boundary between the Lanarkian and Westphalian Series in Yorkshire.[1] The evidence adduced for such a departure appears to us to be far from convincing. Dr. Crookall gives a tabulated and revised list of Yorkshire Coal Measure plants derived from numerous sources, and in his conclusions states that ' the lower portion of the Coal Measures in Scotland, Yorkshire and South Wales is characterised by the presence of *Sphenopteris hoeninghausi* and *Neuropteris rectinervis,* while the latter species has also been discovered in the Millstone Grit of Northumberland. *It is therefore at the top of the lower portion of the Coal Measures that a definite change in the flora occurs in these areas (approximately above the Auchingane Coal in Stirlingshire and below the Silkstone Coal in Yorkshire).*'[2] Four other species are recorded as occurring in the lowest division in Scotland, but these have not hitherto been found in Yorkshire. No other evidence is advanced, and with respect to one of the characteristic species quoted, viz., *Neuropteris rectinervis,* Dr. Crookall admits that it is also known from the lower part of the Middle Coal Measures of Scotland.[3] *Sphenopteris hoeninghausi* on the other hand, appears to be confined to the measures below the Better Bed Coal in Yorkshire. It is one of the commonest plants in the shales above the Halifax Hard Bed Coal and near the base of the Coal Measures. The late R. Kidston had recorded this species from the Middle Coal Measures,[4] though as Dr. Crookall points out, these records are now regarded by Dr. Jongmans as being in error.[5] This species was also recorded by Kidston from the White Rake Bed and the Black Bed, two horizons a short distance above the Better Bed Coal. Dr. Crookall has re-examined the former (Kidston Coll : Geological Survey, No. 812) and informs me that ' it is not *Sphenopteris hoeninghausi,* though it bears some resemblance to the lax form. That from the Black Bed cannot be confirmed as no specimen is available.' It is clear therefore that the records of this species above the Better Bed Coal must be suppressed.

On the evidence that no less than twenty-six Westphalian species occur in the measures above the Better Bed Coal in Yorkshire, the present writer maintains that this horizon marks the upper limit of the Lanarkian. This is in accordance with the generally accepted rule that a younger flora or fauna determines a younger formation; and the occurrence of an occasional

[1] Crookall, R., ' A Critical Revision of Kidston's Coal Measure Floras,' *Proc. Roy. Phys. Soc. Edin.*, vol. xxii, 1931, pp. 1-32.
[2] Crookall, R., *op. cit.*, p. 31.
[3] Crookall, R., *op. cit.*, pp. 3, 11 & 23.
[4] Kidston, R., ' Fossil Plants of the Carboniferous Rocks of Great Britain' (*Mem. Geol. Surv.*, Palaeontology, vol. ii), 1923, p. 327.
[5] Jongmans, W. J., in Jaarverslag over 1929 (1930). *Geologisch Bureau voor het Nederlandsche Mijngebied te Heerlen*, pp. 77-81.

Lanarkian species above that horizon, even if proved, appears to him to be of relatively minor importance.

The Upper Limit of the Yorkian (or Westphalian)

The higher measures are but poorly exposed in Yorkshire and the flora is consequently very imperfectly known. It has been usual, therefore, to refer to the Middle Coal Measures all the beds below the red marls of Conisborough,[1] though Dr. Crookall in summarizing the researches of Kidston and other palaeobotanists places the upper limit of the Yorkian at the horizon of the Houghton Common Rock.[2] In the adjacent coalfield of North Staffordshire the upper measures, being of considerable economic importance, are admirably exposed in a large series of sections, and the floral succession has recently been worked out in considerable detail by Miss E. Dix.[3] The floral evidence in this coalfield clearly indicates that the base of the Staffordian occurs just below the horizon of the Chalky Mine Coal and Ironstone, or within about two hundred feet of the Lady Coal Marine Band and the base of the zone of *Anthracomya phillipsi*. The latter horizon corresponds very closely with the Shafton Marine Band of Yorkshire, and the non-marine lamellibranch succession in the succeeding measures is similar in both coalfields. Thus the fauna of the measures below the Brierley Coal resembles that from the Chalky Mine Ironstone of North Staffordshire,[4] and it seems clear, therefore, that the Staffordian Series is represented in the measures below the Conisborough red marls in Yorkshire. Our knowledge of the limited flora of the higher measures in Yorkshire is almost entirely due to the assiduous collecting of Mr. W. R. Barker of Barnsley and Mr. W. Hemingway of Derby. The remaining records are of isolated specimens found during the sinking of several of the larger collieries.[5]

From the roof of the Shafton Coal at Brierley Colliery Mr. Barker has obtained the following forms:—

Alethopteris lonchitica (Schloth.)
Neuropteris rarinervis Bunb.
Sphenopteris obtusiloba Brongn.
Bothrodendron minutifolium (Boul.)
Sigillaria scutellata Brongn.
Calamostachys sp.
Trigonocarpus oblongus L. & H.
Mariopteris sauveri (Brongn.)
Neuropteris tenuifolia (Schloth.)
Sphenopteris striata Gothan
Lepidodendron sp.
Calamites schützeiformis K. & J.
Artisia transversa (Artis)

The majority of these are of little stratigraphical value, though *Mariopteris sauveri* is not a common plant in Yorkshire and

[1] Green, A. H., 'The Geology of the Yorkshire Coalfield' (*Mem. Geol. Surv.*), 1878, p. 75. Kendall, P. F., and H. E. Wroot, 'The Geology of Yorkshire,' *Leeds*, 1924, p. 185.
[2] Crookall, R., 'A Critical Revision of Kidston's Coal Measure Floras,' *Proc. Roy. Phys. Soc. Edin.*, vol. xxii, 1931, pp. 17, 24 and 32.
[3] Dix, E., 'The Flora of the Upper Portion of the Coal Measures in North Staffordshire,' *Quart. Journ. Geol. Soc.*, vol. lxxxvii, 1931, pp. 160-177.
[4] Wray, D. A., and A. E. Trueman, 'The Non-marine Lamellibranchs of the Upper Carboniferous of Yorkshire and their Zonal Sequence,' 'Summary of Progress' for 1930, Part iii (*Mem. Geol. Surv.*), 1931, p. 90.
[5] Most of the species were identified by the late R. Kidston.

appears to be characteristic of the Shafton Coal. *Neuropteris rarinervis* is quite common in and characteristic of the higher measures in Yorkshire and very rare at lower horizons than the Shafton Coal.

The shales above the Brierley Coal and below the Brierley Rock at Hemsworth yield abundant plant impressions and from Oaklands' Clay Pit, Mr. W. R. Barker has obtained the following:—

Linopteris obliqua Bunb.
Neuropteris rarinervis Bunb.
Sphenopteris sp.
Lepidodendron sp.
Calamites sp.
Sphenophyllum myriophyllum Crépin
Cordaites borassifolius (Sternb.)
Polypterocarpus sp.
Neuropteris gigantea Brongn.
Neuropteris sp.
Cyclopteris sp.
Lepidostrobus sp.
Asterophyllites sp.
Sphenophyllum cf. *wingfieldense* Hem.
Cordaianthus volkmanni (Ett.)

Linopteris obliqua has not hitherto been found below this horizon in Yorkshire, while *Neuropteris rarinervis* is a characteristic species of the higher measures in Yorkshire. The occurrence of *Linopteris obliqua* on this level and its entire absence from lower measures is evidence that these beds belong to the Staffordian Series.

The shales below the Houghton Common Rock at Brierley Common have yielded *Neuropteris scheuchzeri* Hoffm., a plant distinctive of the Transition and Upper Coal Measures. In the same district a group of plants has been obtained from the Houghton Common Rock by Messrs. W. R. Barker and W. Hemingway. Many were obtained by the latter during the construction of the Brierley Tunnel. The complete list is as follows:—

Neuropteris heterophylla Brongn.
Calamites carinatus Sternb.
Annularia sphenophylloides (Zenk.)
Asterophyllites equisetiformis (Schlotheim)
Trigonocarpus oblongus L. & H.
Mariopteris nervosa (Brongn.)
Calamites verticillatus L. & H.
Asterophyllites charaeformis (Sternb.)
Artisia transversa (Artis)
Trigonocarpus parkinsoni Brongn.

All the above forms have been found in the Westphalian (or Yorkian), and with the possible exception of *Annularia sphenophylloides* none could be described as especially distinctive of the higher measures.

A few plants were obtained during the sinking of Cadeby Colliery shafts. These came from the shales above a band of sandstone doubtfully referred to the Ackworth Rock, and about three hundred feet above the Shafton Coal. They include:—

Neuropteris rarinervis Bunb.
Calamites carinatus Sternb.
Asterophyllites equisetiformis (Schloth.)
Cordaites borassifolius (Sternb.)
Eremopteris zamioides (Bertrand)
Annularia sphenophylloides (Zenk.)
Artisia transversa (Artis)

It will be seen from the foregoing lists that although there are a few species characteristic of the higher measures, there is hardly sufficient or convincing evidence from the flora for placing the dividing line between the Staffordian and Yorkian Series anywhere within the measures between the Shafton Marine Band and the Conisborough red marls. While, also, practically all the species recorded occur in the Black Band Series or corresponding measures in North Staffordshire, there is a marked absence in Yorkshire of numerous species distinctive of that group.

The beds between the Shafton Marine Band and the Conisborough red marls exhibit rapid lateral variations, and it is doubtful whether the Houghton Common Rock (the horizon suggested by Dr. Crookall as the base of the Staffordian) can be recognized for more than a mile away from its type locality at Houghton Common, six miles to the east of Barnsley. Its adoption as a major boundary, therefore, would be unfortunate for the stratigrapher. There is, in fact, no index-horizon above the Shafton Marine Band by means of which the succession in different parts of the coalfield can be compared.

The Major Subdivisions

The evidence from the flora and non-marine fauna indicates that one of the principal lines of subdivision in the Yorkshire Coal Measures occurs about the top of the Elland Flags, the line originally chosen as the boundary between the Lower and Middle Coal Measures. Above this horizon is a thick series of sediments with a rich flora which has somewhat vaguely been referred to as the ' Yorkian.' The first pronounced faunal break occurs about the level of the Shafton Marine Band, or the base of the zone of *Anthracomya phillipsi*. The genus *Carbonicola*, so abundant in the Yorkian, is unrepresented above this marine band; and according to Professor Trueman this horizon constitutes a well-marked palaeontological break in the majority of the British coalfields.[1] It seems desirable therefore to adopt this well-defined index horizon as one of the major lines of subdivision, and tentatively as the upper limit of the Yorkian Series.

Conclusions

Numerous attempts have been made within recent years to institute a broad classification of the Coal Measures that could be of wide application, but authorities differ as to the exact lines of demarcation to be adopted between the main subdivisions.

On the Continent, Munier Chalmas and De Lapparent originally included within the Westphalian all the beds now

[1] Trueman, A. E., ' A Note on the Classification of the Coal Measures,' *Geol. Mag.*, 1929, p. 496.

referred to the Upper Carboniferous. Kidston, on the other hand, defined the Westphalian as broadly corresponding to the Middle Coal Measures in Britain. A still further modification was made in 1928 by Dr. Jongmans, who applied the term Westphalian to the Coal Measures as a whole, the Millstone Grit being referred to as the Namurian.[1] Professor Trueman considers that this usage might be tentatively employed until more precise palaeontological information is available, and further adds that the important palaeontological break at the base of the *A. phillipsi* zone may well be adopted as a dividing line between an Upper and Lower Westphalian Series.[2]

Unfortunately the terms 'Lanarkian,' 'Westphalian' (or 'Yorkian'), and 'Staffordian,' which were originally vaguely defined by Kidston on the evidence of their floras, have been somewhat widely employed in Britain as the names of three main stratigraphical subdivisions, though the lack of correspondence in the results obtained by workers on the faunal and floral successions has given rise to much confusion as to their exact connotation. Thus Miss Dix, Dr. Pringle and Professor Trueman state that the measures originally defined by Kidston as Lanarkian, in the type area in Scotland, yield a non-marine fauna corresponding to that of the main part of the Middle Coal Measures (or Yorkian) in England and Wales, and they consequently suggest the abandonment of the terms Lanarkian and Yorkian.[3] On the other hand, Mr. Bisat, recognizing the sharp distinction between the faunas of the marine bands in the Upper and Middle Coal Measures, and those of the Lower Coal Measures, would extend the term Staffordian to include not only the Upper, but also the Middle Coal Measures.[4]

Reviewing the evidence as a whole, there does appear to be fairly general agreement that the Shafton Marine Band or the base of the *A. phillipsi* zone marks one of the principal lines of subdivision in the Coal Measures of England and Wales. It is strongly supported by faunal evidence, and it has been shown above to be not inconsistent with the floral evidence in Yorkshire. There is also an equally marked contrast between the marine faunas in the higher part of the Middle Coal Measures and those of the lowest Coal Measures, the fauna of the latter showing close resemblances to that of the underlying Millstone Grits. The Yorkshire Coal Measures consequently fall into three fairly well-marked divisions, which may tentatively be designated Lanarkian, Yorkian and Staffordian. The Yorkian consisting of some three thousand feet of measures may again be subdivided into

[1] Jongmans, W. J., in *Congrès de Stratigraphie Carbonifère*, Heerlen, 1927 (*Liége*, 1928), p. 394 (Table).
[2] Trueman, A. E., *op. cit.*, p. 499.
[3] Dix, E., J. Pringle and A. E. Trueman, 'The Significance of the term 'Lanarkian Series',' *The Naturalist*, 1930, pp. 325-326.
[4] Bisat, W. S., 'The Carboniferous Goniatite Zones of England,' *Congrès de Stratigraphie Carbonifère*, Heerlen, 1927 (*Liége*, 1928), p. 130, plate vi.

four main groups each characterized by a distinctive fauna. These are as follows (1) The BEESTON GROUP, or the zone of *Carbonicola ovalis*; (2) The PARKGATE AND FLOCKTON GROUP, or zone of *Anthracomya modiolaris*; (3) The BARNSLEY GROUP, the lower part of the '*similis-pulchra*' zone to the Mansfield or Monk Bretton Marine Band; and (4) The CROFTON GROUP, including the measures between the Mansfield and Shafton marine bands.

VI.—THE STRATIGRAPHICAL DISTRIBUTION OF BRITISH LOWER CARBONIFEROUS PLANTS

BY

R. CROOKALL, D.Sc., PH.D.

Text-figures 1 to 3.

INTRODUCTION

IN 1894, the late Dr. R. Kidston[1] published a complete list of the British Carboniferous plant-incrustations then known. In the present account the list is brought up to date so far as the Lower Carboniferous is concerned. Kidston's Distribution Tables indicated merely the presence of a species in a division. An attempt has here been made to show also the relative frequency with which the species occur. It is intended to deal similarly with the Coal Measure incrustations as well as with Carboniferous petrifactions.

Remains of vascular plants are much rarer in the Lower than in the Upper Carboniferous strata. Whereas a large proportion of the latter was deposited in fresh or brackish waters, the bulk of the Lower Carboniferous rocks was deposited under marine conditions.[2] Thus, as a rule, the inclusion and subsequent fossilisation of land plants in Lower Carboniferous strata must have been sporadic. Hence, it has not been found possible to establish satisfactory floral zones in that division, though certain species are restricted to the Calciferous Sandstone Series and others to the Carboniferous Limestone Series in Scotland.

Since the death of Dr. Kidston, in 1924, our increased knowledge of the British Lower Carboniferous flora, and particularly in regard to that of North Wales, has been due to Professor John Walton of Glasgow University. As early as 1889, Kidston[3] recognised the floral relationship of the Teilia Limestones, south of Prestatyn, Flintshire, to the Calciferous Sandstone Series of Scotland, and Professor Walton[4] has recently shown that there is 'substantial evidence for regarding the Teilia Beds as equivalent to the upper part of the Oil Shale Group,' a conclusion which receives faunal support.

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[1] Kidston, R., 'On the Various Divisions of British Carboniferous Rocks as Determined by their Fossil Flora,' *Proc. Roy. Phys. Soc. Edin.*, vol. xii, 1894, pp. 238-257.

[2] The Calciferous Sandstone Series was deposited mainly near land, while the Limestone Coal Group was chiefly laid down in fresh or brackish water.

[3] Kidston, R., 'On some Fossil Plants from Teilia Quarry, Gwaenysgor, near Prestatyn, Flintshire,' *Trans. Roy. Soc. Edin.*, vol. xxxv, 1889, pp. 419-428.

[4] Walton, J., 'Contributions to the Knowledge of Lower Carboniferous Plants,' *Phil. Trans. Roy. Soc. Lond.*, Ser. B, vol. 219, 1931, pp. 347-379.

Reference must be made to the so-called floral break between the Lower and Upper Carboniferous of Britain.[1] This is best dealt with historically. In 1894, Kidston[2] observed, ' I do not know a single species of plant found in the Lower Carboniferous that occurs in the Upper Carboniferous. So far as I have been able to ascertain, there is not in Britain one species common to both of these great divisions.' In a footnote he excepted *Stigmaria ficoides, Lepidostrobus variabilis* and some of the Lepidophylli as unsatisfactory (' aggregate ') species. In 1916, he[3] described the two floras as ' absolutely distinct ' with two exceptions only,[4] observing that, ' only one Lower Carboniferous species, *Lepidodendron veltheimianum* Sternb., passes into the Upper Carboniferous, and this only extends into the Millstone Grit, not passing so far up as the Slatyband,[5] above which there is an entirely different flora.' This statement was based on a more complete account published six years previously,[6] in which *L. veltheimianum* and *L. glincanum* were recorded from supposed Upper Carboniferous rocks. Kidston suppressed the record of the latter species in his 1916 account, and Mr. C. H. Dinham[7] has pointed out that ' the evidence for the Upper Carboniferous age of certain deposits in which these two species were found was at no time decisive. It was merely based on estimates as to whether the natural sections in which they occurred belonged to the upper two-thirds of the Millstone Grit (the top of which was itself an uncertain line). As the considerable unconformity subsequently proved to occur elsewhere in this Series may also exist, as yet undetected, in Midlothian, this criterion of Upper Carboniferous age can no longer be regarded as sound.'

Turning to records of Coal Measure species from the Lower Carboniferous, Kidston[8] observed, ' There is a single plant which, if not specifically identical to *Lepidophloios laricinus* Sternb., is closely related to it, that occurs in the Limestone Coal Group, but the form is so rare in that division as not to be the cause of any palaeontological difficulty.' This exhausts the

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[1] Attention may also be drawn to the abrupt change in the vertical distribution of the so-called estuarine fossil fishes, shown by the late Dr. R. H. Traquair (' Fossil Dipnoi and Ganoidei of Fife and the Lothians,' *Proc. Roy. Soc. Edin.*, vol. xvii, 1891, pp. 384-400 ; ' On the Distribution of Fossil Fish Remains in the Carboniferous Rocks of the Edinburgh District,' *Trans. Roy. Soc. Edin.*, vol. xl, 1903, pp. 687-707). A résumé of the distribution of these and other forms has recently been given by Dr. Murray Macgregor (' Scottish Carboniferous Stratigraphy,' *Trans. Geol. Soc. Glasgow*, vol. xviii, 1928-9, pp. 459-460).

[2] Kidston, R., *op. cit.*, 1894, p. 190.

[3] Kidston, R., in ' The Economic Geology of the Central Coalfield of Scotland (Area V) ' (*Mem. Geol. Surv.*), 1916, p. 124. It should be noted that a second edition of this Memoir was published in 1926, Kidston's observations, though unrevised by him, were there reprinted.

[4] See also E. A. N. Arber, ' The Use of Carboniferous Plants as Zonal Indices,' *Trans. Inst. Mining Eng.*, vol. xxv, 1902-3, p. 377.

[5] The late Dr. G. W. Lee informed me that the faunal evidence of the Slatyband Ironstone is not diagnostic, but that, on stratigraphical grounds, there can be no doubt as to the Upper Carboniferous age of the deposit.

[6] Kidston, R., in ' The Neighbourhood of Edinburgh ' (*Mem. Geol. Surv*), 1910, pp. 244, 384-388.

[7] See also C. H. Dinham in ' The Economic Geology of the Stirling and Clackmannan Coalfield ' (*Mem. Geol. Surv.*), 1932, pp. 117-119 and plate ii.

[8] Kidston, R., *loc. cit.*, 1916.

published records.[1] It may be pointed out, however, that an unpublished record of *Lepidodendron obovatum*, an Upper Carboniferous species, from rocks of Lower Carboniferous age in Stirlingshire, occurs in Dr. Kidston's MS. Distribution Book.[2] The writer has re-examined the specimens, and is by no means satisfied with the identification.[3]

Kidston's latest pronouncement on the 'floral break' was made in 1923[4] when he observed that it was a phenomenon for which he could offer no satisfactory explanation. On the Continent the Carboniferous floras of Belgium and Silesia show no such break.[5] Mr. W. D. Ware, of Swansea, has collected a suite of plants from the lowest portion of the 'Millstone Grit' of Penwyllt,[6] in the Swansea Valley, which the writer found to include both Upper and Lower Carboniferous forms. Mention of these will be made in the forthcoming Merthyr Memoir, but a detailed investigation of the Millstone Grit floras, in South Wales and elsewhere, has been undertaken by Miss E. Dix.[7]

Hitherto we have dealt with incrustations only, but it may be pointed out that *Lepidodrendron harcourti* Witham, a petrified stem, has been recorded from both Upper and Lower Carboniferous rocks. The writer[8] has shown, however, that all the records of the species from the lower division are unsatisfactory. Again, Dr. R. G. Absalom[9] has described a coal-ball flora from Northumberland which consisted of a mixture of Upper and Lower Carboniferous plants, the latter predominating.

Professor E. B. Bailey,[10] accepting, for the time being, Kidston's conclusion as to a plant break[11] in the British Carboniferous and the floral continuity in Belgium and Silesia, has

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[1] *Lepidodendron* cf. *obovatum* has been recorded from the Teilia Beds by Professor Walton.

[2] The horizon given by Kidston reads, 'near top of Millstone Grit,' but should read 'near base of Millstone Grit,' the locality being one-sixteenth of a mile north of the Farmhouse of Gain, Glenboig Station. The specimens (Nos. T 2117 B, T 2120 B) are preserved in the collection of the Scottish Geological Survey. Only the leaf-cushions and the ornamented keel can be discerned.

[3] See, however, the remarks given under *Lepidodendron rhodeanum*.

[4] Kidston, R., 'Fossil Plants of the Carboniferous Rocks of Great Britain' (*Mem. Geol. Surv.*), Palaeontology, vol. ii, 1923-5, p. 10.

[5] Potonié, H., 'Die floristische Gliederung des deutschen Carbon und Perm,' *K. Preuss. geol. Landes., N.F., Heft* 21, 1896, pp. 14, 56, 57; Renier, A. 'Note préliminaire sur la flore de l'assise de phtanites (H Ia) des environs de Liége,' *Ann. de la Soc. géol. de Belgique*, T. xxxiii 1906; and 'La flore du terrain houiller sans houille (H Ia) dans le bassin Couchant de Mons,' *ibid.*, p. 153; also 'Stratigraphie du Westphalien,' *Congrès géol. Internat.*, 1922; J. W. Jongmans, 'Contributions to the Fossil Flora of the Lower Carboniferous,' *in* Van Waterschoot Van Der Gracht, 'The Deeper Geology of the Netherlands,' *Meded. Rijks Opsporing van Delfstoffen*, No. 2, 1909, pp. 269-289.

[6] The writer recently collected plants from the Millstone Grit of Lancashire.

[7] Dix, E., 'The Millstone Grit of Gower,' *Geol. Mag.*, vol. lxviii, 1931, pp. 529-542.

[8] Crookall, R., 'The Horizon of *Lepidodendron harcourti*,' *Annals of Botany*, vol. xlv, 1931, p. 453.

[9] Absalom, R. G., 'The Lower Carboniferous Coal Ball Flora of Haltwistle, Northumberland,' *Proc. Univ. Durham Phil. Soc.*, vol. viii, 1929, p. 73. (Although some of Dr. Absalom's identifications are open to doubt (see, for example, R. Crookall, 'The Genus *Lyginorachis Kidston*,' *Proc. Roy. Soc. Edin.*, vol. li, 1930-1, p. 30), the important conclusion remains that an admixture of Upper and Lower Carboniferous forms occurred in the coal-balls).

[10] Bailey, E. B., 'Plant Migration across the Millstone Grit,' *Geol. Mag.*, vol. lxiii, 1926, pp. 49-61. See also J. W. Jackson, 'Problems in the Classification of the Carboniferous Rocks,' *Journ. Manch. Geol. Assoc.*, vol. i, 1929, pp. 63-78.

[11] In support of the presence of a stratigraphical break, Dr. John Pringle informs me that there appears to be no evidence of the occurrence of the zones H and R of Mr. Bisat's classification in the Scottish Carboniferous. He regards the upper two-thirds of the Millstone Grit of Scotland as probably belonging to the *ovalis* zone.

put forward, as a possible explanation, that ' temporary marine isolation induced a difference in the Carboniferous floral history of the two regions until the spreading deltas of the Millstone Grit provided a highway for plant migration.'

Comparisons with other Floras

Few incrustations of land plants have been recorded from Silurian strata, though on the Continent the following genera have been observed[1]: *Sphenopteridium, Bothrodendron* (*Cyclostigma*), *Knorria* (a condition of the preservation of the latter) and *Stigmaria*.

Although a number of the Lower Carboniferous genera were already present in the Devonian (e.g., *Rhacopteris*), certain forms, in spite of assertions to the contrary in the earlier literature, appear to be absent from the lower rocks. According to Arber[2] these include *Archaeocalamites, Calamites, Adiantites, Cardiopteris, Lepidodendron, Lepidophloios, Sigillaria* and *Cordaites*.

When the British Lower Carboniferous flora is compared with that of the Upper Carboniferous, it will be seen that, though it includes markedly fewer genera and species, the assemblages are by no means unlike. Many groups of plants occur in both divisions. Of these may be noted *Bothrodendron, Sigillaria*[3], *Lepidodendron, Stigmaria, Stigmariopsis, Sphenophyllum, Calamites*[3], *Pecopteris*[3], *Sphenopteris, Neuropteris, Adiantites, Alloiopteris*[3], *Diplotmema, Rhacopteris* and *Rhodea*. On the other hand, some genera are apparently confined to the lower division (*Alcicornopteris, Archaeopteridium, Diplopteridium, Plumatopteris, Spathulopteris* and *Sphenopteridium*), while others have as yet been found in the Upper Carboniferous only (the Cyatheites-Pecopterids, *Alethopteris, Odontopteris*, etc.). In order to bring out the similarities and differences between these two floral assemblages, the chief species are given in the accompanying Tables.

The Upper Carboniferous flora of Britain is to be correlated with the Westphalian of the Continent, even our highest beds—the Radstock Series of Somerset—containing comparatively few of the species characteristic of the Stephanian of France, forms such as *Ptychocarpus unitus* (Brongniart), *Acitheca polymorpha* (Brongniart), *Asterotheca candolleana* (Brongniart), *A. lamuriana* (Brongniart), *A. arborescens* (Schlotheim) and *Dicksonites pluckeneti* (Schlotheim).[4,5,6]

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[1] See W. J. Jongmans, *op. cit.*, 1909, p. 276.

[2] Arber, E. A. N., ' Devonian Floras,' *Cambridge*, 1921, p. 69. See also H. Potonié, Die Silur und die Culm-Flora, *Abh. K. Preuss. Geol. Landes.*, N. F., Heft 36, 1901, and the works of T. G. Halle, R. Kräusel and H. Weyland, W. H. Lang, A. G. Nathorst and O. A. Höeg.

[3] Very rare in the Lower Carboniferous of Britain.

[4] Crookall, R., 'Correlation of the British and French Upper Coal Measures,' 'Summary of Progress' for 1930, Part iii (*Mem. Geol. Surv.*), 1931, pp. 62-69.

[5] Arber, E. A. N., 'The Structure of the South Staffordshire Coalfield, with Special Reference to the Concealed Areas and to the Neighbouring Fields,' *Trans. Inst. Mining Eng.*, vol. lii, Pt. i, 1916, p. 45.

[6] Bertrand, P., ' Stratigraphie du Westphalien et du Stéphanien dans les différents bassins houillers Français,' Congrès de Stratigraphie Carbonifère, Heerlen, 1927, *Liége*, 1928 pp. 93-101.

		SPHENOPHYLLUM	*CORDAITES*	EQUISETALES	
				Calamites	*Asterocalamites*
	UPPER CARBONIFEROUS	*S. emarginatum ;* *S. cuneifolium ;* *S. saxifragaefolium ;* *S. myriophyllum ;* *S. trichomatosum*	*C. angulosostriatus ;* *C. principalis ;* *C. borassifolius ;* *Dorycordaites palmaeformis ;* *Poacordaites microstachys*	Group I[1] *C. suckowi ;* *C. undulatus ;* *C. carinatus ;* *C. cisti*	absent
LOWER CARBONIFEROUS	Carboniferous Limestone Series	*S. tenerrimum* (very rare)	*Cordaites sp.* (very rare)	Group II[2] rare and usually in upper beds only : *C. cistiiformis ;* *C. haueri ;* *C. ramifer ;* *C. taitianus ;* *Volkmannia morrisi*	one species[3] typical : *A. scrobiculatus*
	Calciferous Sandstone Series	? absent	*Cordaites sp.* (very rare)	Group II[2] very rare : *C. approximatiformis ;* *C. roemeri*	ditto

[1] In *Calamites* Group I the ribs on the pith-casts almost always alternate at the nodes.

[2] In *Calamites* Group II the ribs on the pith-casts either alternate at or pass through the nodes (the *Mesocalamites* of Hirmer).

[3] In *Asterocalamites* the ribs on the pith-casts always pass through the nodes. The ribbing is, of course, related to the course of the vascular bundles within the stem so that these variations reflect the anatomical evolution. The narrow leaves *Asterocalamites* are forked (a condition never found in the corresponding leaves of *Calamites-Annularia* and *Asterophyllites*) and the cones contain no sterile bracts.

	FILICALES AND PTERIDOSPERMEAE			
	Pecopterids	Neuropterids	Sphenopterids	Alethopterids
UPPER CARBONIFEROUS	Cyatheites-Pecopterids,[1] e.g. *Asterotheca abbreviata* ; *A. cyathea* ; *A. oreopteridia* ; *A. arborescens* ; *A. crenulata* ; *A. lamuriana* ; *Acitheca polymorpha* ; *Ptychocarpus unitus* ; *Eupecopteris cisti*	*Neuropteris ovata* ; *N. flexuosa* ; *N. rarinervis* ; *N. gigantea* ; *N. tenuifolia* ; *N. heterophylla* ; *N. grangeri* ; *N. microphylla* ; *N. blissi* ; *N. schlehani* *N. callosa* ; *N. obliqua* ;	*Sphenopteris macilenta*; *S. dilatata* ; *S. neuropteroides* ; *S. striata* ; *S. spiniformis* ; *S. laurenti* ; *S. nummularia* ; *S. marrati* ; *S. trifoliolata* ; *S. sewardi* ; *S. woodwardi* ; *Diplotmema furcatum* ;	*Alethopteris serli* ; *A. davreuxi* ; *A. grandini* ; *A. lonchitica* ; *A. decurrens* *A. valida* ; *A. integra* ; *A. oblongata* ; *A. pontica* ; *Lonchopteris bricei* ;
	Pecopterids : *Dactylotheca plumosa*	*Linopteris münsteri* ; *L. obliqua*	*Corynepteris sternbergi* ; *C. coralloides*	*L. rugosa* ; *L. eschweileriana*

[1] The Cyatheites-Pecopterids, as defined by Kidston, include the fertile forms placed in the genera *Asterotheca*, *Scolecopteris*, *Acitheca* and *Ptychocarpus* as well as barren leaves (*Eupecopteris*) with similar shape and venation. Species in which the pinnules are Pecopteroid but not tongue-shaped, with veins generally more lax than in the Cyatheites-Pecopterids (and often Sphenopteroid) are retained under *Pecopteris*, as thus understood. The Cyatheites-Pecopterids are typical of the Upper Coal Measures : species of Pecopteris occur in the Middle and Lower Coal Measures and, more rarely, in the Carboniferous Limestone Series.

THE UPPER AND LOWER CARBONIFEROUS FLORAS—II.—*continued.*

		FILICALES AND PTERIDOSPERMEAE			
		Pecopterids	Neuropterids	Sphenopterids	Alethopterids
LOWER CARBONIFEROUS	Carboniferous Limestone Series	Cyatheites-Pecopterids absent. Pecopterids: *Pecopteris sturi*	? absent	fairly common :— *Diplotmema adiantoides ;* *Sphenopteridium dissectum ;* *Archaeopteridium tschermaki*	absent
	Calciferous Sandstone Series	absent	*Neuropteris antecedens*	fairly common :— *Sphenopteris affine ;* *S. bifida ;* *Sphenopteridium dissectum ;* *S. macconochiei ;* *S. pachyrrachis ;* *S. crassum ;* *S. speciosum ;* *Spathulopteris obovata ;* *S. ettingshauseni ;* *S. decomposita;* *S. dunsi*	absent

		LYCOPODIALES				
		Lepidodendron	*Sigillaria*	*Bothrodendron*	*Asolanus*	*Lepidophloios*
UPPER CARBONIFEROUS		*L. wortheni ;* *L. rimosum ;* *L. dichotomum ;* *L. gaudryi ;* *L. lanceolatum ;* *L. aculeatum ;* *L. lycopodioides ;* *L. obovatum ;* *U. ophiurus*	*S. cumulata ;* *S. laevigata ;* *S. tessellata ;* *S. mammillaris* *U. discophora ;*	*B. minutifolium ;* *B. punctatum*	*A. camptotaenia*	*L. laricinus ;* *L. acerosus*
LOWER CARBONIFEROUS	Carboniferous Limestone Series	common—especially *L. veltheimianum*	very rare— *S. taylori*	? absent	absent	very rare— ? *L. laricinus*
	Calciferous Sandstone Series	ditto, also *L. volkmannianum*	very rare— *S. taylori ;* *S. canobiana ;* *S. youngiana* also *Archaeosigillaria vanuxemi*	very rare— *B. wükianum ;* *B. kidstoni ;* *B. wardiense*	absent	*L. scoticus*

Classification of Lower Carboniferous Rocks

Kidston's classification of the British Lower Carboniferous rocks[1] is appended for reference.

Classification of British Lower Carboniferous Rocks

Series	Group	Scotland	Northumberland and Durham	Midlands, South etc.
CARBONIFEROUS LIMESTONE SERIES	Upper Limestone Group, including part of Millstone Grit[2]	Upper Limestone Group, including part of Millstone Grit[2]	Upper Calcareous Group	Succession of marine limestones and shales
	Limestone Coal Group	Limestone Coal Group	Lickar Coal Group	
	Lower Limestone Group	Lower Limestone Group	Lower Calcareous Group	
CALCIFEROUS SANDSTONE SERIES	Oil Shale Group	Oil Shale Group	Carbonaceous Group (Scremerston Coals)	
	Cementstone Group	Cementstone Group	Tuedian (Fell Sandstones and Cementstones)	

Reference may also be made to Dr. Murray Macgregor's recently published review of the stratigraphy of the Carboniferous rocks of Scotland,[3] to Dr. Douglas Allan's 'Stratigraphy of the British Carboniferous,'[4] to the Carboniferous section of 'Handbook of the Geology of Great Britain,'[5] to Dr. J. W. Jackson's 'Problems in the Classification of the Carboniferous Rocks,'[6] to the writer's[7] recent revision of the terminology of the Coal Measures, to Professor S. H. Reynold's *Report British Assoc., Oxford,* 1926, and to the various papers of Mr. W. S. Bisat.[8]

[1] Kidston R., *op. cit.*, 1923-5, p. 14.
[2] In some areas.
[3] Macgregor, M., *op. cit.*, 1928-9, pp. 442-558.
[4] Allan, D. A., 'The Stratigraphy of the British Carboniferous,' Congrès de Stratigraphie Carbonifère, Heerlen, 1927, published *Liége*, 1928, pp. 1-51.
[5] Kendall, P. F., E. J. Garwood and W. B. Wright, in 'Handbook of the Geology of Great Britain,' ed. by J. W. Evans and C. J. Stubblefield, *London*, 1929, p. 172.
[6] Jackson, J. W., *op. cit.*, 1929.
[7] Crookall, R., 'Coal Measures Terminology,' *The Naturalist*, 1932, p. 111.
[8] Bisat, W. S., 'The Carboniferous Goniatite Zones of England and their Continental Equivalents,' Congrès de Stratigraphie Carbonifère, Heerlen, 1927, published *Liége*, 1928, pp. 117-133, etc.

Plant incrustations have so far been recognised in the following groups in the various counties :—

	Carboniferous Limestone Series			Calciferous Sandstone Series	
	Upper Limestone Group[1]	Limestone Coal Group	Lower Limestone Group	Oil Shale Group	Cement-stone Group
SCOTLAND					
Argyllshire ...	—	×	—	—	—
Arran	×	—	—	×	—
Ayrshire ...	×	×	×	—	—
Berwickshire ...	—	—	—	×	×
Canonbie ...	—	—	—	×	—
Dumbartonshire	×	×	—	×	—
Dumfriesshire ...	—	—	—	×	×
Fifeshire ...	×	×	×	×	—
Haddingtonshire	×	×	—	×	×
Kircudbright-shire	—	—	—	—	×
Lanarkshire ...	×	×	×	×	—
Linlithgowshire	×	×	—	×	—
Midlothian ...	×	×	—	×	—
Peebleshire ...	—	—	×	—	—
Renfrewshire ...	×	—	—	×	×
Roxburghshire...	—	—	—	×	—
Stirlingshire ...	×	—	—	×	—
ENGLAND					
Cumberland ...	—	—	—	×	×
Northumberland	—	—	—	×	×

Yorkshire	Yoredale Series.
Kent	Carboniferous Limestone Series
NORTH WALES	(a) Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland.
	(b) Lower Brown Limestone, very near base of Lower Carboniferous.
SOUTH WALES	Carboniferous Limestone Series.
ISLE OF MAN	(a) Equivalent to Carboniferous Limestone Series.
	(b) Equivalent to Oil Shale Group.

Text-figs. 1—3 (pp. 84, 92 and 98 respectively) illustrate diagrammatically the relative frequency with which the various groups of vascular plants occur as incrustations in the subdivisions of the British Carboniferous.[2] Similar diagrams, to be published later, illustrating the distribution of petrified plants, show interesting differences which are clearly correlated with the conditions of deposition, etc.

[1] In some areas, including part of 'Millstone Grit.'

[2] The dividing-line between the Lanarkian and the Yorkian has been revised since these diagrams were drawn up.

Provisional Synopsis of Genera

LYCOPODIALES	
(1) stems, etc.	Archaeosigillaria *Kidston*, 1901
	Bothrodendron *L. and H.*, 1833
	Lepidodendron *Sternberg*, 1820
	Lepidophloios *Sternberg*, 1825
	Lyginodendron *Gourlie*, 1843
	Sigillaria *Brongniart*, 1822
(2) cones	Lepidostrobus *Brongniart*, 1828
(3) rhizophores or roots	Stigmaria *Brongniart*, 1822
	Stigmariopsis *Grand 'Eury*, 1877
SPHENOPHYLLALES—leaves	Sphenophyllum *Brongniart*, 1822
EQUISETALES	
(1) stems	Asterocalamites *Schimper*, 1862
	Calamites *Suckow*, 1820
(2) cones	Volkmannia *Sternberg*, 1820
FILICALES AND PTERIDOSPERMEAE—leaves	
Group I—Sphenopterideae	Adiantites *Goeppert*, 1836
	Alcicornopteris *Kidston*, 1887
	Alloiopteris *Potonié*, 1899
	Archaeopteridium *Kidston*, 1923
	Diplopteridium *Walton*, 1931
	Diplotmema *Stur*, 1877
	Plumatopteris *Kidston*, 1894
	Rhacopteris *Schimper*, 1869
	Rhodea *Presl*, 1838
	Spathulopteris *Kidston*, 1923
	Spenopteridium *Schimper*, 1874
	Sphenopteris *Brongniart*, 1822
	Telangium *Benson*, 1904
	Zeilleria *Kidston*, 1884
Group II—Pecopterideae	Pecopteris *Brongniart*, 1882 (*Kidston*, 1925)
Group III—Neuropterideae	Neuropteris *Brongniart*, 1822
	Cardiopteris *Schimper*, 1869
FILICALES AND PTERIDOSPERMEAE INCERTAE SEDIS	
(1) stems	Eskdalia *Kidston*, 1903
(2) sporangia	Calathiops *Goeppert*, 1865
	Diplotheca *Kidston*, 1903
	Ootheca *Nathorst*, 1914
	Schuetzia *Geinitz*, 1852
CORDAITALES—leaves	Cordaites *Unger*, 1850
UNASSIGNED GYMNOSPERMOUS SEEDS	
	Boroviczia *Zalessky*, 1905
	Carpolithus *Linnaeus*, 1768
	Rhabdocarpus *Berger*, 1848
	Rhynchogonium *Heer*, 1877
	Samaropsis *Goeppert*, 1864
INCERTAE SEDIS	Pinnularia *L. and H.*, 1834
	Ptilophyton *Dawson*, 1878

Lists of Species

In the lists of species which follow, the frequency with which a given form occurs in the division indicated is shown by numbers, thus: 1–2=very rare; 3–4=fairly rare; 6–7= fairly common; 8–10 = very common.

Although Kidston's great Monograph on the 'Fossil Plants of the Carboniferous Rocks of Great Britain'[1] includes most of the Lower Carboniferous Pteridosperms and Ferns, the Lycopodiales, Sphenophyllales, Cordaitales and Gymnospermous seeds, as well as certain of the Equisetales and unassigned forms, remain to be treated. In the case of the Pteridosperms and Ferns and the Calamites, reference to Kidston's Monograph or to his joint Monograph with Dr. W. J. Jongmans has been thought to be sufficient. Species included under the other groups are described in brief notes, and the reference to the first figure and description is given.[2]

The records are mainly due to Kidston.[3-12] A number has been added from the work of Professor John Walton,[13-16] while some few are due to Arber[17-18] and to the writer.[19] The latter has to thank Professor Walton for kindly looking over the lists.

For the purpose of comparing the vertical distribution of the British with the Continental Lower Carboniferous plants,

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[1] Kidston, R., *op. cit.*, 1923-5.

[2] Kidston observed that 'it is half the battle to know where to look for the description we wish and the original works should in all cases be consulted' ('On the Fructification and Internal structure of Carboniferous Ferns,' *Trans. Geol. Soc. Glasgow*, vol. ix, 1899, p. 2).

[3] Kidston, R., 'Report on Fossil Plants Collected by the Geological Survey of Scotland in Eskdale and Liddesdale,' *Trans. Roy. Soc. Edin.*, vol. xxx, 1883, pp. 531-550.

[4] ——— 'On Some Fossil Plants from Teilia Quarry, Gwaenysgor, near Prestatyn, Flintshire,' *ibid.*, vol. xxxv, 1889, pp. 419-428.

[5] ——— 'On Some New Species of Fossil Plants from the Lower Carboniferous Rocks of Scotland,' *Proc. Roy. Phys. Soc. Edin.*, vol. xii, 1894, pp. 258-268.

[6] ——— 'The Carboniferous Fossil Plants of the Clyde Basin,' *Brit. Assoc. Handbook*, 1901, pp. 468-476.

[7] ——— 'Notes on Carboniferous Plants from Berwickshire,' 'Summary of Progress' for 1900 (*Mem. Geol. Surv.*), 1901, p. 174.

[8] ——— 'The Fossil Plants of the Canonbie Coalfield,' *ibid.*, 1903, pp. 209-216.

[9] ——— 'Lists of Fossils (i) From the Campbelltown Coalfield, (ii) From the Calciferous Sandstone Series of Fife, (iii) From the Neighbourhood of Cocksburnpath, Berwickshire,' *ibid.*, pp. 130-137.

[10] ——— 'The Fossil Plants of the Carboniferous Rocks of Canonbie, Dumfriesshire and parts of Cumberland and Northumberland,' *Trans. Roy. Soc. Edin.*, vol. xl, 1903, pp. 741-883.

[11] ——— 'The Forest of Wyre and the Titterstone Clee Hill Coalfields,' *ibid.*, vol. li, 1917, p. 1065.

[12] ——— 'Fossil Plants of the Carboniferous Rocks of Great Britain' (*Mem. Geol. Surv.*), Palaeontology, vol. ii, 1923-5.

[13] Walton, J., 'Contributions to the Knowledge of Lower Carboniferous Plants,' Parts I, II, *Phil. Trans. Roy. Soc. Lond.*, Ser. B., vol. 215, 1926, pp. 201-224.

[14] ——— Part III, *ibid.*, vol. 219, 1928, pp. 408-410.

[15] ——— 'The Lower Carboniferous Flora of the Menaian Region of Carnarvonshire,' *Quart. Journ. Geol. Soc.*, vol. lxxxiv, 1928, pp. 408-410.

[16] ——— 'A Preliminary Account of the Lower Carboniferous Flora of North Wales,' Congrès de Stratigraphie Carbonifère, Heerlen, 1927, published *Liége*, 1928, pp. 743-746.

[17] Arber, E. A. N., 'A Note on Fossil Plants from the Carboniferous Limestone of Chepstow,' *Geol. Mag.*, vol. iv, 1907, pp. 4, 5.

[18] ——— 'Geology of the Kent Coalfield,' *Trans. Inst. Mining Eng.*, vol. xlvii, 1914, p. 32.

[19] Records by the writer are in Memoirs of the Geological Survey passing through the press, and in *Trans. Nat. Hist. Soc. Northumberland, Durham and Newcastle*, vol. vii, 1931, p. 184 (*in* Hedley, W. P., 'The Stratigraphy of the Bernician,' etc.). Further additions have been made in the Merthyr Memoir.

reference may be made to the works cited below.[1-5] In 1909, Dr. W. J. Jongmans[6] published a valuable review of various Lower Carboniferous floras.

LYCOPODIALES

Archaeosigillaria vanuxemi (Goeppert).

Distribution: England, Carboniferous Limestone Series (3); North Wales (Denbigh and Dyserth), Lower Brown Limestone, very near base of Lower Carboniferous.

Remarks: Originally described by Kidston ('On the Occurrence of *Lycopodites* (*Sigillaria*) *Vanuxemi* Goeppert in Britain, with Remarks on its Affinities,' *Journ. Linn. Soc. Botany*, vol. xxi, 1885, pl. xviii, p. 560) as *Lycopodites*, the plant was transferred by Kidston ('Carboniferous Lycopods and Sphenophylls,' *Trans. Nat. Hist. Soc. Glasgow*, vol. vi, 1901, p. 38) to the new genus, *Archaeosigillaria*. The fructification is unknown. Professor Walton (*op. cit.*, 1913, p. 374) observes, 'The *Archaeosigillaria* horizon would appear to indicate a position very near the base of the Lower Carboniferous in Britain. Outside Britain, it has only been recorded from the base of the Viséan, the Lower Carboniferous of Spitzbergen and the Upper Devonian.' See also Arber, *op. cit.*, 1921, p. 66. *Archaeosigillaria* has not been recorded from the Teilia Beds. The above records are from a much lower horizon at Dyserth, Denbigh and Shap. It occurs in great abundance at Denbigh.

Bothrodendron depereti Vaffier

Distribution: Scotland, Calciferous Sandstone Series (1).

Remarks: This species, described in 1901 by Vaffier (*Étude géol. et paléontol. du Carbonifère Inférieur du Maconnais*, p. 139, pl. xi, fig. 3; pl. xii, fig. 4), was compared and contrasted with *B. wükianum* by Kidston in 1903 (*op. cit.*, 1903, c, p. 134).

Bothrodendron kidstoni Weiss

Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (1); England (Northumberland and Durham), Calciferous Sandstone Series, Cementstone Group (1).

Remarks: The specimen referred to *B. kidstoni* from Northumberland was figured by Kidston ('Additional Notes on Some British Carboniferous Lycopods,' *Proc. Roy. Phys. Soc. Edin.*, vol. x, 1889, pl. iv, fig. 2) as *B. wükianum*. A second specimen (No. 3472), from Dumfriesshire, is in the Kidston Collection.

Bothrodendron wardiense (Kidston MS.) Crookall n.sp.

Distribution: Scotland, Calciferous Sandstone Series (1).

Remarks: This species is represented by specimen No. 26, Kidston Collection. The leaf-scars are larger and wider apart than in *B. kidstoni* or *B. wükianum*. They are 2 mm. high and rather more than 3 mm. across, very clearly marked, and separated vertically by about 2.7 mm. Three cicatricules appear towards the base of the leaf-scar, and 1 mm. above the leaf-scar is the ligule scar. In the other two species the ligule was almost seated on the leaf-scar. As in *B. wükianum*, the lateral angles of the leaf-scar are rounded (in *B. kidstoni* they are typically sharp). *B. wardiense* differs from the last-named in the bark being ornamented by long undulating striae;

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[1] Stur, D., 'Die Culm Flora,' Abhand. d. K. K. geol. Reich., vol. viii, *Wien*, 1875-7.
[2] Gothan, W., 'Leitfossilien,' *Berlin*, 1923.
[3] Potonié, H., 'Die floristische Gliederung des deutschen Carbon und Perm,' *K. Preuss. geol. Landes.*, N.F., Heft 21, 1896, pp. 14, 56.
[4] Patteisky, K., 'Die Begrenzung der sudetischen Stufe des Steinkohlengebirges,' Congrès de Stratigraphie Carbonifère, Heerlen, 1927, *Liége*, 1928, p. 493.
[5] ——— 'Die Geologie und Fossilfuhrung der Mahrischschlesischen Dachschiefer und Grauwackenformation,' Naturw. Verein, *Troppau*, 1929.
[6] Jongmans, W. J. *op. cit.*, 1909, p. 272.

these curve round the leaf-scar, leaving, above and below it, a smooth region. Specimens of *B. wükianum* are markedly smaller than *B. wardiense*, the ligule closer to the leaf-scar, and the cicatricules not shown. See also remarks under *B. wükianum*.

Bothrodendron wükianum (Heer)

Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (1); England (Northumberland and Durham), Calciferous Sandstone Series (1).

Remarks: This species was originally referred by Heer (*Foss. Flora d. Bären Insel*, p. 40, pl. vii, fig. 1c, pl. viii, fig. 2c; pl. ix, fig. 1) to *Lepidodendron*. Kidston (*op. cit.*, 1889, b, pl. iv, figs. 2-4, p. 65) described and figured three specimens as *B. wükianum*, comparing them with Heer's plant. These are now known to represent three distinct species. His fig. 2 is *B. kidstoni*; fig. 3 *B. wükianum* and fig. 4 *B. wardiense*. Kidston recognised the distinctness of the last-named and suggested the specific name, but left no description or diagnosis.

Lepidodendron cf. *calamitoides* Nathorst

Distribution: North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).

Remarks: A specimen, provisionally referred to Nathorst's species (*K. Svenska Vetensk. Akad. Handl.*, vol. 26, No. 4), was figured by Professor Walton (*op. cit.*, 1931, pl. 26, fig. 30, p. 370). The leaf-cushions are not sufficiently well preserved for exact determination.

Lepidodendron jaschei Roemer

Distribution: Scotland, Carboniferous Limestone Series, Limestone Coal Group (2); North Wales, upper part of Lower Carboniferous (1).

Remarks: (See Roemer, F. A., *Palaeontographica*, vol. xiii, 1850-1866, p. 213, pl. xxxv, fig. 6). In 1886, Kidston ('Catalogue of the Palaeozoic Plants in the Department of Geology and Palaeontology, British Museum (Natural History),' *London*, 1886, pp. 162, 167) regarded this species as a young condition of *L. veltheimianum*. It is distinguished from *L. nathorsti* by the much finer cortical ornament and by the clearness with which the cicatricules are shown.

Lepidodendron glincanum (Eichwald)

Distribution: Scotland, Carboniferous Limestone Series, Limestone Coal Group (2).

Remarks: *L. glincanum*, described under the genus *Sagenaria* by Eichwald (Lethaea rossica ou Paléontologie de la Russie, *Stuttgart*, 1853-60, vol. i, p. 127, pl. v, figs. 21, 22; pl. va, figs. 1-6), is very variable. On the younger branches the leaf-cushions are spirally arranged, as in *L. veltheimianum*, but on old stems they are vertical, as in *L. volkmannianum*. As a result, the species have been confused. In 1886 Kidston (*op. cit.*, 1886, a, pp. 162, 166) united it with the former, but in 1903 (*op. cit.*, 1903, e, p. 762) regarded it as distinct. Specimens from the Upper Carboniferous of Bristol compared by D. G. Lillie (*Geol. Mag.*, vol. vii, 1910, pl. vii, figs. 1-3, text-figs. 4, 5, p. 63) with *L. glincanum* are probably Zeiller's *L. dichotomum*.

Lepidodendron nathorsti Kidston

Distribution: Scotland, ? Carboniferous Limestone Series, Upper Limestone Group (1); Calciferous Sandstone Series (1).

Remarks: A drawing of the type was first given in 1885 by Kidston ('On the Relationship of *Ulodendron*, Lindley and Hutton, to *Lepidodendron* Sternberg, *Bothrodendron*, Lindley and Hutton, *Sigillaria* Brongniart and *Rhytidodendron* Boulay,' *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi, 1885, fig. 3) as *L. veltheimianum*. It was not until 1914 that it was figured as *L. nathorsti*. The cortex bears a characteristic ornamentation consisting in numerous, closely placed, oblique striae. This feature at once distinguishes *L. nathorsti* from the somewhat similar *L. jaschei*.

Lepidodendron cf. *obovatum* Sternberg

Distribution: North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).

Remarks: This record, from Teilia, is due to Professor Walton (*op. cit.*, 1931, pl. 25, fig. 28, p. 370). It ' might belong to several species, but, according to Dr. W. J. Jongmans, most nearly resembles *L. obovatum.*' Sternberg's species was described in his *Essai flore monde prim.*, vol. 1, 1820, fasc. i, pp. 21, 25, pl. iv, fig. i, pl. viii, figs. 1A, a, b; fasc. 4, p. x.

Lepidodendron rhodeanum Sternberg

Distribution: Scotland, Carboniferous Limestone Series (4); Calciferous Sandstone Series (3).

Remarks: In 1886 Kidston (*op. cit.* 1886, a, p. 160) recorded this plant from both the Upper and Lower Carboniferous of Britain, but in 1894 (' On *Lepidophloios* and on the British species of the Genus,' *Trans. Roy. Soc. Edin.*, vol. xxxvii, 1893, p. 251) pointed out that it is restricted to the latter division. Arber (*Sci. Proc. Roy. Dublin Soc.*, vol. xiii, N.S., No. 12, pl. xii, fig. 12, p. 172) compared an Irish specimen with the species. There can be no doubt as to their identity. *L. rhodeanum* shows great resemblance to *L. obovatum.* (See C. von Sternberg, *Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt*, fasc. iv, p. xi).

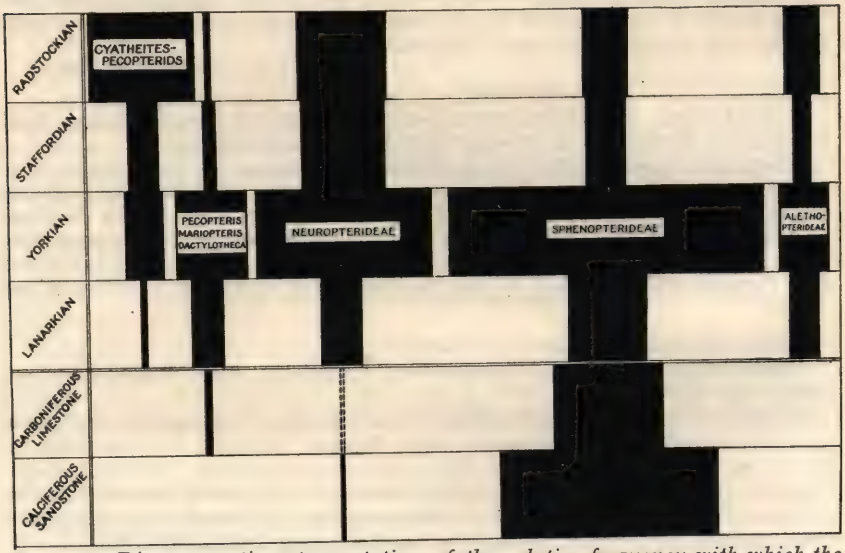

FIG. 1.—*Diagrammatic representation of the relative frequency with which the various groups of vascular plants occur as incrustations in British Carboniferous rocks.*

Lepidodendron spetsbergense Nathorst

Distribution: Scotland, Carboniferous Limestone Series (1).

Remark: Species described in *Nordost-Grönland*, vol. iii, 1914, p. 344, pl. xvi, fig. 24.

Lepidodendron veltheimianum Sternberg

Distribution: Scotland, Carboniferous Limestone Series (8), Calciferous Sandstone Series, Oil Shale Group (7); England (Northumberland and Durham), Calciferous Sandstone Series, Oil Shale Group (1), Cementstone Group (1).

Remarks: This is the most frequent and most widely distributed Lycopod in our Lower Carboniferous rocks. It was figured in 1826 by Sternberg (*Essai flore monde prim.*, vol. i, fasc. iv, p. 48, pl. lii, fig. 3). The leaf-cushions are

comparatively large, rhomboidal and prominent, contiguous on the young branches, separate on the old, and arranged in spirals (see remarks on *L. glincanum*). Many stems of this species bear Ulodendroid scars (probably representing the sites of deciduous branches).

Lepidodendron volkmannianum Sternberg

Distribution: Scotland, Carboniferous Limestone Series, Lower Limestone Group (1), Calciferous Sandstone Series, Oil Shale Group (1); England (Northumberland and Durham), Calciferous Sandstone Series, Oil Shale Group (1).

Remarks: This species was figured (un-named) by Rhode in 1821. In 1826 it was named by Sternberg (*Vers. Darstell. Flora Vorwelt*, vol. i, pt. iv, p. 44, pl. liii, fig. 3, a, b, c). The leaf-cushions are in vertical series. They are contiguous and vary from rhomboidal to club-shaped. The prominent keel bears a series of well-marked transverse ridges. In 1912, Arber (*op. cit.*, 1912, pl. x, fig. 1, pl. xii, fig. 14, p. 171) recorded a specimen from the Ballycastle Coalfield, Ireland. Potonié described an example which showed alternate zones of larger and smaller leaf-cushions, a feature which is commoner in the genus *Sigillaria* than in *Lepidodendron*. See also Prof. A. C. Seward, 'Fossil Plants,' *Cambridge*, vol. ii, 1910, p. 105.

Lepidodendron sp.

Distribution: North Wales, Lower Brown Limestone, very near base of Lower Carboniferous, Dyserth (1); Denbigh (1).

Cf. *Lepidodendron sp.* ('*Knorria*')

Distribution: Basement Series of Menaian region (1).

Remark: This record is due to Professor Walton (*op. cit.*, 1928, p. 410).

Lyginodendron landsburgi Gourlie

Distribution: Scotland, Carboniferous Limestone Series (1).

Remarks: This 'genus' was instituted in 1843 by W. Gourlie (*Proc. Phil. Soc. Glasgow*, vol. i, 1842-3, pl. ii, p. 108), but it merely includes old stems of *Lepidodendron*. See R. Crookall 'The Genus *Lyginorachis* Kidston,' *Proc. Roy. Soc. Edin.*, vol. li, 1930-1, p. 33.

Lepidophloios ? laricinus Sternberg

Distribution: Scotland, Carboniferous Limestone Series, Limestone Coal Group (1).

Remarks: *L. laricinus*, described in 1820 (Sternberg's *Essai*, vol. i, fasc. i, pp. 23, 25, pl. xi, figs. 2-4), is an Upper Carboniferous form. The keel is scarcely visible. The lateral angles of the scars are very sharp.

Lepidophloios ? macrolepidotus Goldenberg

Distribution: Scotland, Carboniferous Limestone Series (1).

Remarks: This plant was first described as *Lomatophloios macrolepidotum* by Goldenberg (*Flora Saraep foss.*, heft i, p. 22) and figured in 1862 (*ibid.*, heft iii, p. 37, pl. xiv, fig. 25). In 1893, Kidston (*op. cit.*, 1893, f, p. 560) recorded a poorly preserved *Lepidophloios* from Grange, Linlithgowshire, provisionally comparing it with Goldenberg's species, but at the same time pointing out that this 'species' is of doubtful value, as the type-specimen may represent only an old stem of *L. acerosus*, or, more probably, a large-cushioned form of *L. laricinus*.

Lepidophloios scoticus Kidston

Distribution: Scotland, Calciferous Sandstone Series (6).

Remarks: *L. scoticus* was first figured by Macfarlane as *L. laricinus* (*Trans. Bot. Soc. Edin.*, vol. xiv, 1883, pl. vii, viii, figs. 1, ? 2, 3, 4, 5b, 5c (not 5a), p. 181). There is no keel (except in specimen No. 2404, Kidston Coll.), and the smooth, rounded, elongated leaf-cushions at once separate it from the other species. Spirally arranged circular scars with a central vascular

scar occur and were regarded by Kidston (*op. cit.*, 1893, f, p. 561) as representing the origin of stalked cones. Decorticated branches bearing such organs are referred to *Halonia*. The circular scars may, in some instances, represent the point of attachment of cones, but in others they were the origins of deciduous branches. *Lepidostrobus comosus* is probably the cone of this species.

In 1901, Kidston (*op. cit.*, 1901, a, p. 55) recorded a specimen of *L. scoticus* from the Carboniferous Limestone Series of Linlithgowshire. This was in error, and he altered the horizon in his Register to the Calciferous Sandstone Series.

Lepidophyllum fisheri n. sp.

Distribution: England, Scremerston Series, Sills Burn, 334 yds. W. of High Rochester, 500 yds. up-stream from Rochester Bridge, Northumberland.

Remarks: This species is at present represented by a single specimen collected by Mr. W. D. Fisher and preserved in the collection of the Scottish Geological Survey, Edinburgh (No. V 2487 B). The bract is linear-lanceolate, acuminate, single veined, 4 cm. long by 4 mm. broad at the widest point (situated at 5 mm. from the base). It tapers fairly suddenly from this point for a further 5 mm. to a width of 3 mm., after which the margins approach each other more gradually, giving a characteristic long point.

Lepidophyllum lanceolatum see *Lepidostrobus*

Lepidostrobus comosus Lindley and Hutton

Distribution: Scotland, Calciferous Sandstone Series (1).

Remarks: Lindley and Hutton ('Fossil Flora of Great Britain,' *London*, 1831-7, vol. iii, pl. 162) observed that their species was distinguished from other species of *Lepidostrobus* by its greater size, its conical shape and by 'the very shaggy appearance of its outside' (due to the long overlapping bracts). Kidston (*op. cit.*, 1886, a, p. 196), observing that specimens sometimes bore *Lepidophloios* leaf-scars, believed it to be the cone of *L. scoticus*.

Lepidostrobus fimbriatus Kidston

Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (2), Cementstone Group (6); England (Northumberland and Durham), Carbonaceous Group (6).

Remarks: This species, described in 1883 (Kidston, 1883, e, Eskdale, p. 543, pl. xxxi, figs. 2-4), represents detached heart-shaped bracts with sharp points and prominent midribs. A single sporangium is situated near the base of each bract. The characteristic feature is the strongly fimbriated margin of the upper portion of the bract. As only bracts are known, it is uncertain to what genus *L. fimbriatus* belongs.

Lepidostrobus lanceolatus (Lindley and Hutton)

Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (6); England (Northumberland and Durham) (1).

Remarks: These bracts are ill-defined and were no doubt derived from several distinct species of cone. They have no stratigraphical value. See Lindley and Hutton, 'Fossil Flora,' pl. vii, figs. 3, 4.

Lepidostrobus variabilis Lindley and Hutton

Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (6).

Remarks: *L. variabilis*, figured in the *Fossil Flora*, vol. i, pl. x, pl. xi (the figure to the right only), is an 'aggregate species,' useless in stratigraphy. It was recorded by Kidston (*op. cit.*, 1883, e, p. 543) as frequent in the Calciferous Sandstones of Scotland as well as occurring in the Upper Carboniferous (Kidston, *op. cit.*, 1894, a, p.251).

Lycopodites plumula Dawson, see *Ptilophyton*

Lycopodites vanuxemi (Goeppert) see *Archaeosigillaria*

Lycopodites stocki Kidston

Distribution : Scotland, Calciferous Sandstone Series (1).

Remarks : This species was founded on a single specimen measuring 4 inches long. Of this, 1¼ inches is represented by an incomplete terminal cone. Kidston (' On a New Species of *Lycopodites* Goldenberg (*L. stockii*) from the Calciferous Sandstone Series of Scotland,' *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xiv, 1884, p. 116) was inclined to regard the plant as having borne two kinds of leaves : (a) some rather more than ¼ inch long, ovate cordate, with acuminate apices, and (b) smaller ' leaves ' which were transversely oval and bore a superficial resemblance to sporangia. Professor F. O. Bower ('Origin of a Land Flora,' *London*, 1908) regarded the latter as sporangia, though no spores have been found. In 1901, Kidston (*op. cit.*, 1901, a, p. 38) still held to the foliar view.

Sagenaria depressa Goeppert see *Lepidodendron rhodeanum*

Sigillaria canobiana Kidston

Distribution : Scotland, Carboniferous Limestone Series (6).

Remarks : This is one of the two ribbed *Sigillariae* known from the British Lower Carboniferous. The recent statement that *Sigillaria* is unknown from the Lower Carboniferous is untrue. See Kidston, 1903, e, p. 765, pl. iii, fig. 26; pl. iv, figs. 29-35 ; pl. v, figs. 46, 47. The specimens in the Kidston Collection are pyritised and falling to pieces. The species stands nearest to the Upper Carboniferous *S. polyploca* Boulay. Though in both the ribs are inflated, in *S. polyploca* the scar does not occupy the whole width between the ribs ; it is more elongated and stands a little above the inflation. In *S. youngiana* there is a much greater contraction and expansion of the ribs—just below the leaf-scars they are twice as wide as midway between them—and the interfoliar cortex above the scar bears fine short usually vertical lines.

Sigillaria taylori (Carruthers)

Distribution : Scotland, Carboniferous Limestone Series (2), Calciferous Sandstone Series (7).

Remarks : Under the name *Ulodendron taylori*, Carruthers (*Monthly Micro. Journ.*, vol. iii, 1870, pl. xliii, fig. 1, p. 125) figured a Lycopod stem bearing indistinct leaf-scars. In 1885, Kidston (*op. cit.*, 1885, e, pl. iv, fig. 6, p. 239) figured an example of the species as *Sigillaria*, showing the Ulodendroid condition. In *S. taylori* the leaf-scars are practically contiguous and each scar appears to bear a single cicatricule (Kidston *op. cit.*, 1886, a, p. 179). An interesting specimen (No. T. 843), collected by Mr. D. Tait from close to the top of the Carboniferous Limestone Series at Longdike Burn, a mile E. of Brockenfield Bridge and 1¼ miles W. of Eshottheugh, Scotland, was identified by the writer as *S. taylori*. It is remarkable as showing well-defined leaf-scars.

Sigillaria vanuxemi Goeppert see *Archaeosigillaria*

Sigillaria youngiana Kidston

Distribution : Scotland, Carboniferous Limestone Series, Possil Ironstone Group (=Limestone Coal Group) (1).

Remarks : *S. youngiana* was described in 1894 (Kidston, *op. cit.*, 1894, b, p. 261, pl. vi, figs. 2, 2a). See also observations with regard to *S. canobiana*. This species resembles the Upper Carboniferous *S. contracta* Brongniart in the alternately contracted and expanded ribs, but differs from *S. contracta* in the leaf-scars being longer than broad and in their situation, namely, on the contracted portions of the ribs, while the lateral angles are feebly developed. The approximately vertical ornamentation of the ribs in *S. youngiana* is also distinctive.

Stigmaria ficoides (Sternberg)

Distribution: Scotland, Carboniferous Limestone Series, Limestone Coal Group (8), Calciferous Sandstone Series, Oil Shale Group (3), Cementstone Group (3); England (Northumberland and Durham), Carbonaceous Group (4).

Remarks: Described as *Variolaria ficoides* in 1820, by Sternberg (*Essai*, vol. i, fasc. i, pp. 23, 26; pl. xii, figs. 1-3), this is a non-zonal form.

Stigmaria ficoides, var. *undulata* Goeppert

Distribution: Scotland, Calciferous Sandstone Series, ? Cementstone Group (1); England (Northumberland and Durham) ? Carbonaceous Group (1).

Remarks: Also a non-zonal fossil, occurring in both Upper and Lower Carboniferous rocks. It was figured by Goeppert in 1841 (*Gatt. d. foss. Pflanzen.*, Lief 1-2, pp. 13, 30, pl. ix, figs. 5-8 (? f. 9)). Rootlet scars vary in size with the age of the organ. Between the scars, in this 'species,' are clearly marked undulating lines which bend round the scar.

Stigmaria stellata Goeppert see *Stigmariopsis*

Cf. *Stigmaria sp.*

Distribution: Basement Series of Menaian Region (1).

Remarks: Professor Walton (*op. cit.*, 1928, p. 409) notes the presence of very numerous fragments of what appear to be Stigmarian rootlets, one specimen showing dichotomy. In the absence of Stigmarian axes, he hesitates, however, definitely to record *Stigmaria.*

Stigmariopsis rimosa (Goldenberg)

Distribution: Scotland, Carboniferous Limestone Series (1).

Remarks: *Stigmariopsis* is shorter and thicker than *Stigmaria* and the bark bears an irregular network of lines. *S. rimosa* was described by Goldenberg (*Flora Saraep. foss.*, heft iii, p. 15, figs. 3-6) as *Stigmaria rimosa*, though the name given on the plate is *S. abbreviata*. It is non-zonal, occurring in both the Upper and the Lower Carboniferous, though the form is more frequent in the latter. Comparatively coarse, somewhat distant lines ornament the cortex and tend to bend round the rootlet scars.

Stigmariopsis rimosiformis (Kidston)

Distribution: Scotland, Carboniferous Limestone Series, Limestone Coal Group (1).

Remarks: The cortex bears a number of delicate flexuous lines which radiate from the scars. They are much finer and more closely placed than in *S. rimosa* (in which form the lines also tend to bend round the scars).

Stigmariopsis stellata (Goeppert)

Distribution: Scotland, Carboniferous Limestone Series (4).

Remarks: *S. stellata* was described as *Stigmaria ficoides*, var. *stellata* by Goeppert in 1841 (*Gatt. d. foss. Pflanzen*, Lief 1, 2, p. 13, pl. x, fig. 12). Although Kidston (*op. cit.*, 1894, a, p. 254) recorded *S. stellata* from the Calciferous Sandstones of Scotland, I know of no definite records. The species was also listed by him ('List of Fossil Plants collected in the Neighbourhood of Bo'ness,' Appendix B, *in* H. M. Cadell, 'The Fossiliferous Rocks of Barrowstounness,' 1883, p. 335) in 1883. A number of specimens from the Carboniferous Limestone are preserved in the Kidston Collection. Ridges radiate in a stellate manner from the rootlet-scars. Most authors regard *S. stellata* as a variety of *Stigmaria ficoides*. In 1886 Kidston (*op. cit.*, 1886, a, p. 204) recorded it from the Coal Measures only, but later (*op. cit.*, 1894, a, p. 254) omitted the Coal Measure record and listed it from both divisions of the Lower Carboniferous. As observed above, the Calciferous Sandstone Series records require confirmation.

SPHENOPHYLLALES

Sphenophyllum tenerrimum Stur

Distribution : Scotland, Carboniferous Limestone Series (1), Calciferous Sandstone Series (2).

Remarks : *S. tenerrimum* was figured by Stur in 1877 (*Culm Flora*, Part II, p. 108, pl. vii (xxiv), figs. 1-14. In 1883, Kidston (' On the Affinities of the Genus *Pothocites*, Paterson, with the Description of a specimen from Glencartholm, Eskdale,' *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xi, 1883, pl. ix-xii, pp. 309, 314) mentioned and figured three examples of *S. tenerrimum*. A specimen (No. 156) is in the Kidston Collection. The leaves are in whorls of 6 or more, with a diameter of 6-20 mm. They are narrow and linear, forking once or twice (occasionally three times). Stems measure 2-3 mm. across with internodes 12 or 13 mm. long.

EQUISETALES

Archaeocalamites scrobiculatus (Schlotheim) see *Asterocalamites*

Archaeocalamites radiatus Stur see *Asterocalamites*

Asterocalamites scrobiculatus (Schlotheim)

Distribution : Scotland, Carboniferous Limestone Series (5), Calciferous Sandstone Series, Oil Shale Group (2) ; England (Northumberland and Durham), Oil Shale Group (2) ; North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (3).

Remarks : *A. scrobiculatus* was described in 1820 (as *Calamites*) by Schlotheim (*Petrefactenkunde*, p. 402, pl. xx, fig. 4). In *Asterocalamites* the ribs are continuous through the nodes and the leaves fork (at once distinguishing them from *Calamites*). The linear leaves may fork repeatedly. The fructification of the species is *Pothocites grantoni* Paterson. (See Kidston, *op. cit.*, 1883, c, p. 305 ; 1903, e, p. 753). Branching is irregular, some casts bearing branch-scars on many nodes, others none. Professor Walton (*op. cit.*, 1931, pl. 26, fig. 39, p. 369) has figured an excellent specimen from Teilia.

Calamites approximatiformis Stur

Distribution : Scotland, Calciferous Sandstone Series (1).

Remarks : I know of only one record of this species, the specimen being preserved in the Royal Scottish Museum, Edinburgh. The casts seldom show alternation of the ribs (and therefore approach *Asterocalamites*). Dr. R. Kidston and Dr. W. J. Jongmans (' A Monograph of the Calamites of Western Europe, ' vol. i of ' Flora of the Carboniferous of the Netherlands and Adjacent Regions ' by W. J. Jongmans, *Gravenhage*, 1917 (text), 1915 (Atlas), p. 203) observe that the specimen is distinguished from *A. scrobiculatus* ' by its distinct and prominent ribs with their large oval tubercles and the distribution of the branch scars.' The branch-scars (about 3 mm. diameter) occur irregularly and the upper surface of the ribs bears fine longitudinal striations.

Calamites cistiiformis Stur

Distribution : Scotland, Carboniferous Limestone Series, Upper Limestone Group (4).

Remarks : See Stur's *Culm Flora*, pl. iv (21), figs. 5, 6, p. 200 and Kidston and Jongmans (*op. cit.*, 1915, 1917, p. 192). Some ribs alternate at the nodes, others pass through. The straight furrows are bounded by a double line. Branch-scars are small and rare. In *C. cisti*, according to Kidston and Jongmans, the ribs are of the alternating type only, and their ends are rounded : in *C. cistiiformis* those ribs which alternate have sharply pointed ends.

Calamites dilatatus Goeppert see *C. roemeri*

Calamites haueri Stur

Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (4).

Remarks: See Stur's *Culm Flora*, pl. xix, fig. 7; pl. xxii, figs. 2, 3, p. 195, and Kidston and Jongmans (*op. cit.*, 1915, 1917, p. 197). Many of the ribs do not alternate at the nodes, and those which do end in sharp points (contrast *C. suckowi*). The surface of the ribs bears cross-hatching.

Calamites ramifer Stur

Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (2).

Remarks: Kidston and Jongmans (*op. cit.*, 1915, 1917, p. 200) exclude one of Stur's figures (4) as *C. cistiiformis*. (Stur, *Culm Flora*, pl. xx, figs. 3, 3b, 4; pl. xxi, figs. 2, 3; exclude fig. 4 and text-figs. 15-17 on p. 155, 156 and 18 on p. 192). Each node generally bears branch-scars (varying from 1 to 5) which are up to 5 mm. in diameter. Working on imperfect material, some authors have confused *C. ramifer* with *C. carinatus* (=*C. ramosus*).

Calamites roemeri Goeppert

Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (2), Calciferous Sandstone Series (1).

Remarks: See Goeppert *in* Roemer, *Palaeontographica*, III, pl. vii, fig. 6, p. 45, 1850 and Kidston and Jongmans (1915, 1917), p. 188. Some ribs alternate (ending in sharp points), others do not. The branch-scars are characteristically verticillate, about 1 cm. in diameter, circular, slightly distant, with an eccentric umbilicus. The species is distinguished from all others of Group II by having wide furrows with a longitudinally striated surface, by the large oval tubercles and verticillate branching. It is separated from *C. undulatus* by the non-alternation of many ribs and by the absence of cross-hatching.

Calamites radiatus Schimper see *Asterocalamites scrobiculatus*

Calamites taitianus Kidston and Jongmans

Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (4), Limestone Coal Group (1).

Remarks: See Kidston and Jongmans (*op. cit.*, 1915, p. 195). *C. taitaianus* resembles *C. carinatus*, but in the latter non-alternation of the ribs is absent and each node generally bears 2 (rarely 1 or 3) branch-scars. In *C. taitianus* the branch-scars, though somewhat irregular, are usually in two opposite rows, one on every second node.

Calamites transitionis Goeppert see *Asterocalamites scrobiculatus*

Calamites sp. England (Northumberland), Bernician (1).

Pinnularia sp.

Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (1); England (Northumberland and Durham), Carbonaceous Group = Oil Shale Group of Midlothian (1).

Remark: These roots have no stratigraphical value.

Pothocites calamitoides Kidston see *Asterocalamites scrobiculatus*

Pothocites grantoni Paterson see *Asterocalamites scrobiculatus*

Volkmannia morrisi Hooker

Distribution: Scotland, Carboniferous Limestone Series (1).

Remarks: I know of only one record of this species, the type, described in 1854 (*Quart. Journ. Geol. Soc.*, vol. x, 1854, pl. vii, p. 199). Plaster casts of the specimen are preserved in the Museum of Practical Geology and in the British Museum (Natural History). It came from Carluke, Lanarkshire and belongs to Mr. W. Gourlie of Glasgow. See Kidston (*op. cit.*, 1886, a, p. 55).

Volkmannia sp.
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (1).

FILICALES AND PTERIDOSPERMEAE

(1) PECOPTERIDEAE

Dactylotheca sturi Sterzel pro var. see *Pecopteris*

Pecopteris sturi Sterzel
Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (4).
Remarks: It is doubtful whether this species should be listed under *Pecopteris* or *Sphenopteris*. Kidston (*op. cit.*, 1923-5, p. 395) placed it in *Dactylotheca*, but Prof. Walton points out that the sporangium had an annulus.

(2) NEUROPTERIDEAE

Cardiopteris frondosa (Goeppert)
Distribution: Scotland, Calciferous Sandstone Series (4).

Cardiopteris nana (Eichwald)
Distribution: Scotland, Carboniferous Limestone Series (2).

Cyclopteris frondosa Goeppert see *Cardiopteris*

Cyclopteris haidingeri Ettingshausen see *Cardiopteris frondosa*

Cyclopteris hochstetteri Stur see *Cardiopteris polymorpha*

Cyclopteris koechlini Schimper see *Cardiopteris frondosa*

Cyclopteris polymorpha Goeppert see *Cardiopteris*

Cardiopteris polymorpha (Goeppert)
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (1); England (Northumberland and Durham), Carbonaceous Group (1), See Kidston (*op. cit.*, 1886, a, p. 84). Pinnules may be opposite or alternate.

Cardiopteris polymorpha, var. *rotundifolia* Goeppert
Distribution: Scotland, Carboniferous Limestone Series (1), Calciferous Sandstone Series (1).

Neuropteris antecedens Stur
Distribution: Scotland, Carboniferous Limestone Series (of Lanarkshire) (1); England, Carboniferous Limestone Series (of Pembrokeshire) (1), Pendleside Series (of Pembrokeshire) (1); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks: This species is unsatisfactory. See Stur's *Culm Flora*, pl. xv, figs. 1-6, p. 53. Professor Walton (*op. cit.*, 1931, pl. 25, figs. 25, 26, p. 364) figured two specimens from Teilia.

Neuropteris heterophylla Feistmantel (*non* Brongniart) see *N. antecedens*

Neuropteris loshii Feistmantel (*non* Brongniart) see *N. antecedens*

(3) SPHENOPTERIDEAE

Alloiopteris quercifolia (Goeppert)
Distribution: England (Staffordshire), Carboniferous Limestone Series (in rocks probably equivalent to Upper Limestone Group of Scotland) (1).
Remark: See Kidston (*op. cit.*, 1923-5, p. 306).

Adiantites antiquus (Ettingshausen)

Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (3); England (Northumberland), Cementstone Group (1); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1); Isle of Man, Carboniferous Limestone Series (1).

Remark: See Kidston (*op. cit.*, 1923-5, p. 187) and Walton (*op. cit.*, 1931, p. 354).

Adiantites machaneki (Stur)

Distribution: Scotland, Lower Limestone Group (1); Isle of Man, Carboniferous Limestone Series (1); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (4).

Remark: See Kidston (*op. cit.* 1923-5, p. 189) and Walton (*op. cit.*, 1931, p. 355).

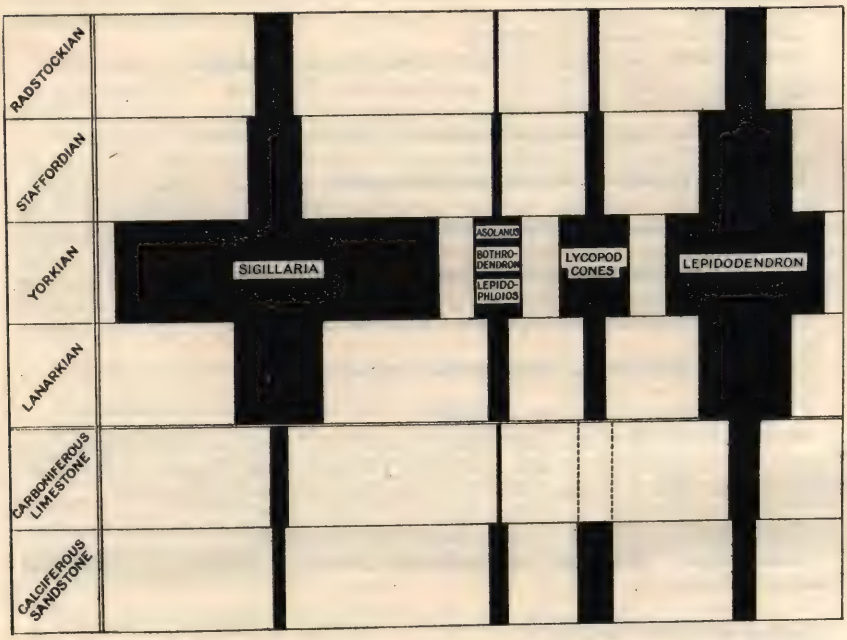

FIG. 2.—*Diagrammatic representation of the relative frequency with which the various groups of vascular plants occur as incrustations in British Carboniferous rocks.*

Adiantites tenuifolius (Goeppert)

Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (1), Calciferous Sandstone Series, Oil Shale Group (2); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).

Remark: See Kidston (*op. cit.*, 1923-5, p. 193) and Walton (*op. cit.*, 1931, p. 356).

Adiantites sp.

Distribution: North Wales, upper part of Lower Carboniferous (1).

Remark: A doubtful specimen was recorded by Professor Walton from Teilia (*op. cit.*, 1931, p. 356).

Alcicornopteris convoluta Kidston
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (2), Cementstone Group (7) ; England (Northumberland), Cementstone Group (2).
Remark : See Kidston (*op. cit.*, 1923-5, p. 418).

Alcicornopteris zeilleri Vaffier
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 421).

Alcicornopteris sp.
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (1) ; Wales, Basement Series of Menaian Region (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 423).

Archaeopteridium tschermaki (Stur)
Distribution : Scotland, Carboniferous Limestone Series, Limestone Coal Group (1), Lower Limestone Group (4), Calciferous Sandstone Series, Oil Shale Group (3).
Remark : See Kidston (*op. cit.*, 1923-5, p. 182).

Archaeopteris dissecta Stur see *Sphenopteridium*

Archaeopteris lyra Stur see *Sphenopteridium dissectum*

Archaeopteris reussi (Ettingshausen) see *Palaeopteridium*

Archaeopteris tschermaki Stur see *Archaeopteridium*

Cf. *Coseleya sp.*
Distribution : Scotland, Calciferous Sandstone Series, Cementstone Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 370).

Diplopteridium teilianum (Kidston)
Distribution : North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland.
Remarks : This was originally described as a *Sphenopteris* by Kidston (*op. cit.*, 1889, d, pl. ii, fig. 3, p. 424) who, in 1923 (*op. cit.*, 1923-5, pl. ii, fig. 5, pl. xix, figs. 6, 6a, p. 96), described the rachis as forking into two equal parts. Professor Walton (' Contributions to the Knowledge of Lower Carboniferous Plants,' *Phil. Trans. Roy. Soc. Lond.* ser. B, vol. 215, p. 212) in 1926 showed that Kidston's specimens were imperfect and that a third rachis occurred in the angle of the fork, the frond being probably pinnate. In 1931, Professor Walton (*op. cit.*, 1931, p. 349) described synangia which, though not in organic connection, undoubtedly belonged to the frond. He instituted the genus *Diplopteridium* to receive Kidston's species,observing that it is now 'the most completely known frond, from the point of view of external morphology, of any Lower Carboniferous plant.' It was probably a Pteridosperm.

Diplotmema adiantoides (Schlotheim)
Distribution : Scotland, Carboniferous Limestone Series, Upper Limestone Group (10), Limestone Coal Group (10), Calciferous Sandstone Series, Oil Shale Group (1) ; England (Northumberland), Carbonaceous Group (=Oil Shale Group of Midlothian) (1), (Yorkshire), Yoredale Series (1).
Remarks : This is the *Sphenopteris elegans* of Brongniart. The surface of the petiole bears longitudinal striations and vertical rows of transverse bars (i.e., the Heterangium type of cortex). The venation has not been observed. See Kidston (*op. cit.*, 1923-5, p. 242).

Diplotmema bermudensiforme (Schlotheim)
Distribution: Scotland, Carboniferous Limestone Series, Limestone Coal Group (2), Lower Limestone Group (1), Calciferous Sandstone Series, Oil Shale Group (1); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks: See Kidston (*op. cit.*, 1923-5, p. 250). Professor Walton (*op. cit.* 1931, p. 357) includes *S. schonknechti* under this species.

Diplotmema dissectum (Brongniart)
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (4); England (Northumberland), Scremerston Beds (1), North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks: See Kidston (1923-5, p. 248). Professor Walton (*op. cit.*, 1931, p. 357) points out that Bureau's *Calymmatotheca lineariloba* is indistinguishable from this species.

Diplotmema elegans Stur see *D. adiantoides*

Diplotmema patentissimum (Ettingshausen)
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (2), Cementstone Group (1); England (Cumberland), Cementstone Group (1), (Northumberland) Carbonaceous Group (1); North Wales, upper part of Lower Carboniferous (1).
Remark: See Kidston (*op. cit.*, 1923-5, p. 253.)

Calymmatotheca affinis (Lindley and Hutton) see *Sphenopteris*

Calymmatotheca bifida (Lindley and Hutton) see *Sphenopteris*

Calymmatotheca lineariloba Bureau see *Diplotmema dissectum*

Calymmatotheca stangeri Stur
Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (4); England (Wharfedale), Yoredale Group (1).
Remark: see Kidston (*op. cit.*, 1923-5, p. 465).

Filicites elegans Brongniart see *Diplotmema adiantoides*

Gleichenites linki Goeppert see *Sphenopteris fragilis*

Plumatopteris elegans Kidston
Distribution: Scotland, Carboniferous Limestone Series, Lower Limestone Group (2).
Remark: See Kidston (*op. cit.*, 1923-5, p. 185).

Rhacopteris circularis Walton
Distribution: North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (6).
Remarks: See Walton (*op. cit.*, 1926, pl. 16, figs. 5-8; pl. 17, figs. 13, 14, p. 208; *op. cit.*, 1931, p. 362) who points out that his species most closely resembles *R. inaequilatera* and *R. lindseaeformis* and that specimen No. 3308, Kidston Coll., labelled '*R. lindseaeformis*' is referable to *R. circularis*. This is described as one of the commonest plants in the Teilia Beds.

Rhacopteris dichotoma Kidston
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (1).
Remark: See Kidston (*op. cit.*, 1923-5, p. 215).

Rhacopteris fertilis Walton
Distribution : North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks : This species, which 'probably represents the fertile frond of one of the other species, perhaps *R. circularis*,' is represented by a single specimen from Teilia (see Walton, *op. cit.*, 1926, pl. 16, figs. 2-4, p. 205).

Rhacopteris flabellata (Tate) see *R. petiolata*

Rhacopteris geikiei Kidston
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (3).
Remark : See Kidston (*op. cit.*, 1923-5, p. 217).

Rhacopteris inaequilatera (Goeppert)
Distribution : Scotland, Carboniferous Limestone Series, Limestone Coal Group (1), Lower Limestone Group (1), Calciferous Sandstone Series, Oil Shale Group (4), Cementstone Group (2).
Remark : See Kidston (*op. cit.*, 1923-5, p. 208) and Walton (*op. cit.*, 1926, p. 205).

Rhacopteris lindseaeformis (Bunbury)
Distribution : Scotland, Carboniferous Limestone Series, Lower Limestone Group (2), Calciferous Sandstone Series, Oil Shale Group (7) ; North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 205) and Walton (*op. cit.*, 1926, p. 205 and 1931, p. 363).

Rhacopteris machaneki Stur
Distribution : North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remark : A single record is due to Professor Walton (*op. cit.*, 1931, pl. 25, fig. 20, p. 362).

Rhacopteris petiolata (Goeppert)
Distribution : Scotland, Carboniferous Limestone Series, Lower Limestone Group (1), Calciferous Sandstone Series, Oil Shale Group (3) ; England (Northumberland), Calciferous Sandstone Series, Oil Shale Group (1), Lancashire, Lower Carboniferous (1) ; North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 211) and Walton (*op. cit.*, 1926, p. 209).

Rhacopteris robusta Kidston
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (1) ; North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks : See Kidston (1923-5, p. 216) and Walton (*op. cit.*, 1931, p. 363). Specimens compared with *R. petiolata* in 1916 (*op. cit.* p. 210) were later transferred to Kidston's *R. robusta*.

Rhacopteris subcuneata Kidston
Distribution : England (Northumberland), Calciferous Sandstone Series, Oil Shale Group (2) ; ?North Wales, Lower Brown Limestone, very near base of Lower Carboniferous, Dyserth (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 217), and Walton (*op. cit.*, 1928, p. 745).

Rhacopteris transitionis Stur
Distribution : Scotland, Carboniferous Limestone Series, Limestone Coal Group (1), Lower Limestone Group (2), Calciferous Sandstone Series, Oil Shale Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 219).

Rhacopteris weissi Walton see *Sphenopteris*

Rhacopteris sp.
Distribution : North Wales, Denbigh Lower Brown Limestone, very near base of Lower Carboniferous (1).

Rhodea feistmanteli Kidston
Distribution : England (Staffordshire), Carboniferous Limestone Series (? on horizon of Upper Limestone Group of Scotland) (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 235).

Rhodea gigantea Stur
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 225).

Rhodea goepperti (Ettingshausen)
Distribution : Scotland, Lower Carboniferous (1) ; also ? Carboniferous Limestone Series, Upper Limestone Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 233).

Rhodea machaneki (Ettingshausen)
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (1), Cementstone Group (1).
Remark : See Kidston (*op cit.*, 1923-5, p. 228).

Rhodea smithi Kidston
Distribution : Scotland (Ayrshire only), ? Calciferous Sandstone Series (4).
Remark : See Kidston (*op. cit.*, 1923-5, p. 226).

Rhodea tenuis Gothan
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (2) ; North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (5).
Remarks : See Kidston (*op. cit.*, 1923-5, p. 229), and Walton (*op. cit.*, 1931, p. 360). The latter observes that *R. tenuis* is one of the commonest species at Teilia and that it shows great variation in form.

Rhodea sp.
Distribution : Wales, Basement Series of Menaian region (1).
Remark : Recorded by Professor Walton (*op. cit.*, 1928, p. 410).

Spathulopteris clavigera (Kidston)
Distribution : Scotland, Carboniferous Limestone Series, Lower Limestone Group (1), Calciferous Sandstone Series, Oil Shale Group (1) ; North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1) ; (Yorkshire) horizon equivalent to low down in the Upper Limestone Series of Scotland (1).
Remarks : See Kidston (*op. cit.*, 1923-5, p. 142) and Walton (*op. cit.*, 1931, p. 361). The Yorkshire record is due to the latter and was collected by Mr. W. S. Bisat from an horizon characterised by the goniatite *Anthracoceras glabrum.*

Spathulopteris ettingshauseni (Feistmantel)
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (2) ; England, Upper Limestone Series (1) ; North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 177) and Walton (*op. cit.*, 1931, p. 361).

Spathulopteris decomposita (Kidston)
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (3) ; England (Northumberland), Oil Shale Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 178).

Spathulopteris dunsi Kidston
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (4).
Remark : See Kidston (*op. cit.*, 1923-5, p. 180).

Spathulopteris haueri (Stur)
Remarks : Kidston (*op. cit.*, 1894, a, p. 240) listed *Sphenopteris haueri* as occurring in the Carboniferous Limestone Series of Scotland. In 1923 he (*op. cit.*, 1923-5, p. 172) excluded it from the list of British plants and observed that the species should probably be referred to *Spathulopteris*.

Spathulopteris obovata (Lindley and Hutton)
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (3).
Remark : See Kidston (*op. cit.*, 1923-5, p. 173).

Sphenopteris affine Lindley and Hutton
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (10) ; England (Tynedale), Oil Shale Group (1) ; Isle of Man, (?) Oil Shale Group (1).
Remarks : This is a very common and characteristic species of the Oil Shale Group ; it appears to be restricted to that division. See Kidston (*op. cit.*, 1923-5, p. 446). Walton (*op. cit.*, 1931), points out that Kidston does not appear to be justified in referring *S. affinis* and *S. bifida* to *Telangium*, as there is no evidence of continuity between the sterile fronds and the *Telangium* fructifications. In 1928 (*op. cit.*, p. 410) he recorded rachises of the *S. affinis* type from the Basement Series of the Menaian region.

Sphenopteris bifida Lindley and Hutton
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (8) ; England (Northumberland), Oil Shale Group (5) ; Isle of Man (?) Oil Shale Group (1).
Remarks : See above (under *S. affine*) and Kidston (*op. cit.*, 1923-5, p. 454). This is another very typical plant in the Oil Shale Group (to which it appears to be confined). It is, however, less frequent than *S. affine* and its distribution more localised.

Sphenopteris clavigera Kidston see *Spathulopteris*

Sphenopteris crassa Lindley and Hutton see *Sphenopteridium*

Sphenopteris cuneolatum Lindley and Hutton
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (2).
Remarks : See Kidston (*op. cit.*, 1923-5, p. 156). Lindley and Hutton (*Fossil Flora*, vol. iii, pl. ccxiv) merely listed their plant from the Newcastle Coalfield. Schimper (1874) pointed out that it was of a Lower Carboniferous type.

Sphenopteris cymbiformis Kidston
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (3).
Remarks : See Kidston (*op. cit.*, 1923-5, p. 145). When specimens showing the venation are found, this rare species will probably be transferred to the genus *Spathulopteris*.

Sphenopteris decomposita Kidston see *Spathulopteris*

Sphenopteris dicksonioides (Goeppert)

Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (4), Limestone Coal Group (3); England (Northumberland), Oil Shale Group (1), Bernician—underlying Thornborough Limestone (1).

Remarks: A rare species readily recognised by the small convex pinnules with rounded lobes. See Kidston (*op. cit.*, 1923-5, p. 73).

Sphenopteris distans Stur see *Diplotmema bermudensiforme*

Sphenopteris dunsi Kidston see *Spathulopteris*

Sphenopteris elegans Brongniart see *Diplotmema adiantoides*

Sphenopteris ettingshauseni Feistmantel see *Spathulopteris*

Sphenopteris excelsa Lindley and Hutton see *Spathulopteris obovata.*

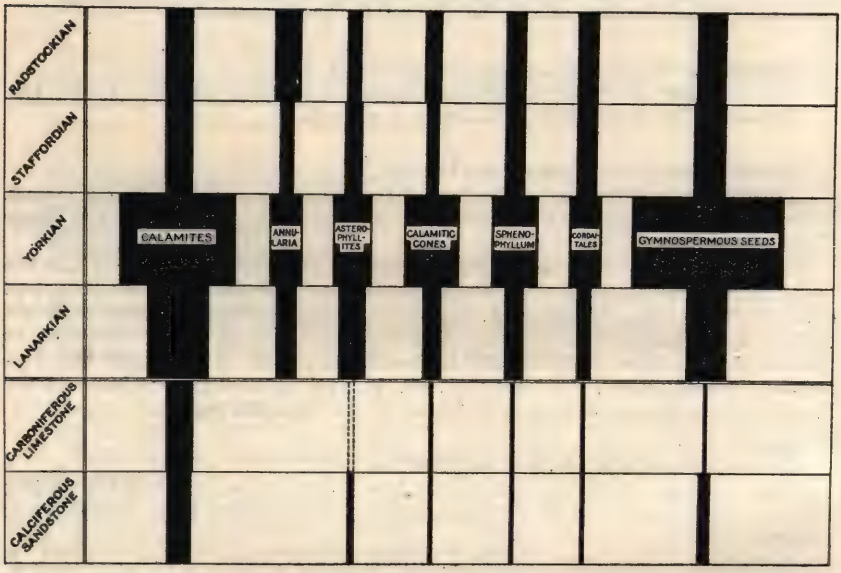

FIG. 3.—*Diagrammatic representation of the relative frequency with which the various groups of vascular plants occur as incrustations in British Carboniferous rocks.*

Sphenopteris falkenhaini Stur

Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (1); ? England (Northumberland), Bernician (1).

Sphenopteris filiformis Kidston

Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (2); England (Northumberland), Carboniferous Limestone Series (1); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (?1).

Remarks: The record of this species from Northumberland is based on an identification by the writer. The specimen is in the Geological Survey collection at Edinburgh (No. GB. 97). In 1928, Professor Walton ('A Preliminary Account of the Lower Carboniferous Flora of North Wales and its Relation to the Floras of some other parts of Europe,' Congrès de Stratigraphie Carbonifère, Heerlen, 1927, *Liége*, 1928, p. 743), recorded *S. filiformis* from North Wales, but in 1931 (*op. cit.*, p. 364) queried the record and observed 'I am inclined to think that *S. filiformis* Kidston represents nothing more than an immature form of some other better defined genus.' See Kidston (*op. cit.*, 1923-5, p. 95).

Sphenopteris foliolata Stur
Distribution : Scotland, Carboniferous Limestone Series, Upper Limestone Group (1), Calciferous Sandstone Series, Oil Shale Group (3).
Remarks : This species shows similarities to the Upper Carboniferous *S. shillingsi* Andrae. See Kidston (*op. cit.*, 1923-5, p. 113).

Sphenopteris fragilis (Schlotheim)
Distribution : Scotland, Carboniferous Limestone Series, Upper Limestone Group (7), Limestone Coal Group (5).
Remarks : This plant is somewhat locally distributed. See Kidston (*op. cit.*, 1923-5, p. 86).

Sphenopteris gersdorfi (Goeppert) see *Spathulopteris clavigera*
Remarks : In 1894, Kidston (*op. cit.*, p. 241) listed *S. gersdorfi* and in 1923 (*op. cit.*, p. 142) included the record under *Spathulopteris clavigera*.

Sphenopteris haueri Stur see *Spathulopteris*

Sphenopteris hibberti Lindley and Hutton
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (1).
Remarks : *S. hibberti* is represented by the type only. This is lost and the accuracy of the figure is doubtful. See Kidston (*op. cit.*, 1923-5, p. 66).

Sphenopteris hochstetteri (Stur) see *Rhodea gigantea*

Sphenopteris johnstoniana Tate see *Diplotmema adiantoides*

Sphenopteris kirkbyi Kidston
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (2).
Remarks : *S. kirkbyi* shows a general resemblance to the Upper Carboniferous *S. sauveuri* Crépin. See Kidston (*op. cit.*, 1923-5, p. 114).

Sphenopteris linki (Goeppert) see *S. fragilis*

Sphenopteris macconochiei Kidston see *Sphenopteridium*

Sphenopteris mira Kidston
Distribution : Scotland, Carboniferous Limestone Series, Upper Limestone Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 138).

Sphenopteris moravica Kidston *non* Ettingshausen see *Sphenopteridium capillare*

Sphenopteris obfalcata Walton
Distribution : North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (5).
Remarks : This species was described in 1931 by Professor Walton (*op. cit.*, 1931, pl. 25, fig. 27, text-fig. 6, p. 363), who records 'numerous specimens ' from Teilia.

Sphenopteris pachyrrachis Goeppert see *Sphenopteridium*

Sphenopteris petiolata Goeppert see *Rhacopteris*

Sphenopteris schönknechti (Stur) see *Diplotmema bermudensiforme*

Sphenopteris subgeniculata (Stur) see *Rhodea tenuis*

Sphenopteris taitiana Kidston
Distribution : Scotland, Carboniferous Limestone Series, Upper Limestone Group (2).
Remark : See Kidston (*op. cit.*, 1923-5, p. 78).

Sphenopteris teiliana Kidston see *Diplopteridium*

Sphenopteris (*Rhacopteris*) *weissii* Walton
Distribution: North Wales (Dyserth), Lower Brown Limestone, very near base of Lower Carboniferous (1).
Remarks: Recorded by Professor Walton (*op. cit.*, 1928, p. 745).

Sphenopteridium capillare Walton
Distribution: Scotland, Carboniferous Limestone Series, Upper Limestone Group (4), Limestone Coal Group (1), Calciferous Sandstone Series, Oil Shale Group (5); England (Wharfedale), Yoredale Group (1); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks: See Walton (*op. cit.*, 1931, p. 358). This is the *Sphenopteris moravica* Kidston *non* Ett.

Sphenopteridium crassum (Lindley and Hutton)
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (5); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks: This should probably be united to *S. pachyrrachis*. See Kidston (*op. cit.*, 1923-5, p. 168) and Walton (*op. cit.*, 1931, p. 360).

Sphenopteridium dissectum (Goeppert)
Distribution: Scotland, Upper Limestone Group (1), Limestone Coal Group (1), Lower Limestone Group (2), Calciferous Sandstone Series, Oil Shale Group (3); England (Northumberland), Bernician—underlying Thornbrough Limestone (1).
Remarks: See Kidston (*op. cit.*, 1923-5, p. 160).

Sphenopteridium macconochiei (Kidston)
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (1).
Remarks: See Kidston (*op. cit.*, 1923-5, p. 163).

Sphenopteridium pachyrrachis (Goeppert)
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (6), Cementstone Group (2); England, Carboniferous Limestone Series (1); North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remarks: See Kidston (*op. cit.*, 1923-5, p. 164) and Walton (*op. cit.*, 1931, p. 360).

Sphenopteridium speciosum Kidston
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (1).
Remarks: See Kidston (*op. cit.*, 1923-5, p. 170).

Telangium affinum (Lindley and Hutton) see *Sphenopteris*

Telangium bifidum (Lindley and Hutton) see *Sphenopteris*

Zeilleria moravica Kidston *non* Ettingshausen see *Sphenopteridium capillare*

FILICALES AND PTERIDOSPERMEAE INCERTAE SEDIS

Aneimites acadica Dawson
Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (2).
Remarks: See Kidston (*op. cit.*, 1923-5, p. 414).

Caulopteris minuta Kidston see *Eskdalia*

Calathiops acicularis Goeppert
Distribution : North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remark : See Walton (*op. cit.*, 1931, p. 366).

Calathiops glomerata Walton
Distribution : North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remark : See Walton (*op. cit.*, 1931, p. 367).

Calathiops renieri Walton
Distribution : North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (1).
Remark : See Walton (*op. cit.*, 1931, p. 367).

Calathiops sp.
Distribution : Scotland, Calciferous Sandstone Series (1).
Remarks : This is the specimen listed by Kidston (*op. cit.*, 1923-5, p. 473) as *Pterispermostrobus.*

Diplotheca stellata Kidston
Distribution : Scotland, Carboniferous Limestone Series, Limestone Coal Group (1).
Remark : See Kidston (*op. cit.*, 1923-5, p. 472).

Eskdalia minuta (Kidston)
Distribution : Scotland, Calciferous Sandstone Series, Oil Shale Group (2) ; England (Northumberland), Cementstone Series (1).
Remarks : The species is regarded as representing a fern stem. See Kidston (*op. cit.*, 1903, e, pl. i, figs. 4-8, p. 750).

Ootheca globosa Kidston
Distribution : Scotland, Calciferous Sandstone Series, Cementstone Group (1).
Remarks : A single record. See Kidston (*op. cit.*, 1923-5, p. 371).

Pterispermostrobus see *Calathiops*

Schuetzia bennieana Kidston
Distribution : Scotland, ? Carboniferous Limestone Series, Upper Lime stone Group (1), Calciferous Sandstone Series, Oil Shale Group (2).
Remarks : Kidston (*op. cit.*, 1923-5, p. 425) and Walton (*op. cit.*, 1931 p. 465).

CORDAITALES

Cordaites sp.
Distribution : Scotland, Carboniferous Limestone Series (1), Calciferous Sandstone Series, Oil Shale Group (1) ; England (Kent), Carboniferous Limestone Series (1).
Remarks : The Kent record is due to Arber (*op. cit.*, 1914, p. 32) who observed that in the Carboniferous Limestone Series of Kent plants are very rare. This is the only record.

UNASSIGNED GYMNOSPERMOUS SEEDS

Boroviczia gloagiana (Young)
Distribution : Scotland, Carboniferous Limestone Series (1).
Remarks : In 1869 Young (*Proc. Nat. Hist. Soc. Glasgow*, vol. i, 1858-69, pl. iv, figs. 9, 10, p. 203) figured two seeds as '*Trigonocarpum* ? ' observing that, while there was a general resemblance to that genus, the upper third of his seeds was composed of a longitudinally ribbed beak, the remainder being

smooth. In 1876, Young (*Catalogue of the Western Scottish Fossils* by J. Armstrong, p. 36) referred to the seeds as *T. gloagianum*, and Kidston (*op. cit.*, 1894, a, p. 256) listed them under that name. They are now referred to Zalessky's *Boroviczia* (ovate beaked seeds), differing from Heer's *Rhynchogonium* only in the more marked differentiation of the apex. Specimen in Young Coll., Hunterian Museum, University of Glasgow.

Cardiocarpus apiculatus Kidston see *Carpolithus planus*

Cardiocarpus bicaudatus Kidston see *Samaropsis*

Cardiocarpus nervosus Kidston see *Samaropsis*

Cardiocarpus planus Kidston see *Carpolithus*

Carpolithus planus (Kidston)
Distribution: England (Northumberland and Durham), Carbonaceous Group (2).
Remarks: Specimens originally recorded by Kidston (*op. cit.*, 1883, e, pl. xxxi, fig. 13, p. 545) as ? *Cardiocarpus apiculatus* were re-described by him (*op. cit.*, 1903, e, p. 826) as *Cordaicarpus planus* · they are now placed in *Carpolithus* Linn. The seeds may be pointed or oval, about 7 mm. long by 6 mm. broad. The surface is smooth and there is a very narrow wing-like border.

Carpolithus sulcata Lindley and Hutton see *Rhynchogonium*

Carpolithus sp.
Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (1); North Wales, upper part of Lower Carboniferous (1).

Cordaicarpus bicaudatus (Kidston) see *Samaropsis*

Cordaicarpus planus Kidston see *Carpolithus*

Holcospermum ellipsoideum (Goeppert)
Distribution: North Wales, Teilia Beds, equivalent to upper part of Oil Shale Group of Scotland (3).
Remarks: Professor Walton (*op. cit.*, 1931, p. 368) recording several seeds under this name observes ' It is possible that this species merely represents a state of preservation of a seed which if better preserved, might have been placed in either *Rhynchogonium* or *Boroviczia*.'

Rhabdocarpus curvatus Kidston
Distribution: England (Northumberland and Durham), Carbonaceous Group (2).
Remarks: *R. curvatus* was described in 1903 by Kidston (*op. cit.*, 1903, e, pl. ii, fig. 14, p. 826) as an oblong seed varying in length from 1.3 to 2 cm. and in breadth from 0.5 to 0.7 cm., blunt at each end, slightly curved, and bearing about 8 slight ridges. The only known specimens are those in the Museum of Practical Geology (No. 48789).

Rhynchogonium costatum Heer
Distribution: Scotland, Calciferous Sandstone Series (1).
Remarks: For a description of this species see Professor A. C. Seward's ' Fossil Plants,' *Cambridge*, vol. iii, 1917, p. 358, text-fig. 506 G.

Rhynchogonium sulcatum (Lindley and Hutton)
Distribution: Scotland, Carboniferous Limestone Series (1).
Remarks: This seed was described by Lindley and Hutton (*op. cit.*, 1831-7, vol. iii, pl. 220) as *Carpolithes sulcata* and was listed by Kidston (*op. cit.*, 1894,

a, p. 256). Zakessky (*Bull. Acad. Imp. Sci. St. Pétersbourg*, T. xxii, No. iii, pp. 118, 119) figured specimens from the Kidston Collection. Its association with pinnules of *Cardiopteris* may be significant. Professor Seward (*op. cit.*, 1917, p. 358) observes that some specimens in the Kidston collection show the original surface features of the seed.

Samaropsis bicaudata (Kidston)

Distribution: Scotland, Calciferous Sandstone Series, Cementstone Group (2).

Remarks: Originally figured and listed by Kidston ('On Some New Species of Fossil Plants from the Lower Carboniferous Rocks of Scotland,' *Proc. Roy. Phys. Soc. Edin.*, vol. xii, 1894, pl. vi, figs. 3, 4, p. 267; also *op. cit.*, 1894, a, p. 255) as *Cardiocarpus*, this seed was referred in 1902 ('The Flora of the Carboniferous Period'—Second Paper—*Proc. Yorks. Geol. and Polytech. Soc.*, vol. xiv, pt. iii, pl. lviii, figs. 5, 6, p. 367) to *Samaropsis*. The chief distinguishing feature consists in the two tail-like downward extensions of the membranous wing.

Samaropsis nervosa (Kidston)

Distribution: England (Northumberland and Durham), Cementstone Group (1).

Remarks: This species also was originally placed under *Cardiocarpus* by Kidston (*op. cit.*, 1894, a, p. 255; 1894, b, pl. iv, figs. 3-5, p. 266). The characteristic feature is the strongly developed vein-like markings extending from the margins of the nucule to the margin of the wing.

Trigonocarpum ellipsoideum Goeppert see *Holcospermum*

Trigonocarpum gloagianum Young see *Boroviczia*

INCERTAE SEDIS

Ptilophyton plumula (Dawson)

Distribution: Scotland, Calciferous Sandstone Series, Oil Shale Group (1); England (Northumberland and Durham), Calciferous Sandstone Series (1).

Remarks: See Dawson ('Report on Fossil Plants of Lower Carboniferous and Millstone Grit Forms, Canada,' *Geol. Surv. Canada*, 1873, pl. i, figs. 7-9, p. 24) and Kidston (*op. cit.*, 1903, e, p. 759).

List of Dr. Kidston's Works Cited

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1883 e 'Report of Fossil Plants collected by the Geological Survey of Scotland in Eskdale and Liddesdale,' *Trans. Roy. Soc. Edin.*, vol. xxx, pp. 531-550.

1883 f 'List of Fossil Plants collected in the Neighbourhood of Bo'ness (Appendix B, *in* H. M. Cadell, 'The Fossiliferous Rocks of Barrowstounness'), *Trans. Geol. Soc. Edin.*, vol. iv, p. 333-335.

1884 f 'On a New Species of *Lycopodites* Goldenberg (*L. stockii*) from the Calciferous Sandstone Series of Scotland,' *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xiv, pp. 111-117.

1885 d 'On the Occurrence of *Lycopodites* (*Sigillaria*) *Vanuxemi* Goeppert, in Britain, with Remarks on its Affinities,' *Journ. Linn. Soc. Bot.*, vol. xxi, 1885, pp. 560-566.

1885 e ' On the Relationship of *Ulodendron*, Lindley and Hutton, to *Lepidodendron* Sternberg, *Bothrodendron* Lindley and Hutton, *Sigillaria* Brongniart and *Rhytidodendron* Boulay,' *Ann. and Mag. Nat. Hist.*, ser. 5, vol. xvi, 1885, pp. 123-139; 162-179; 239-260.

1886 a ' Catalogue of the Palaeozoic Plants in the Department of Geology and Palaeontology, British Museum (Natural History),' *London*, 1886.

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1889 c ' Additional Notes on some British Carboniferous Lycopods,' *Ann. and Mag. Nat. Hist.*, ser. 6, vol. iv, pp. 60-67.

1889 d ' On some Fossil Plants from Teilia Quarry, Gwaenysgor, near Prestatyn, Flintshire,' *Trans. Roy. Soc. Edin.*, vol. xxxv, 1889, pp. 419-428.

1891 a ' On the Fructification and Internal Structure of Carboniferous Ferns in their Relation to those of Existing Genera, with Special Reference to British Palaeozoic Species,' *Trans. Geol. Soc. Glasgow*, vol. ix, 1891, pp. 1-56.

1893 f ' On *Lepidophloios*, and on the British Species of the Genus,' *ibid.*, vol. xxxvii, 1893, pp. 529-563.

1894 a ' On the Various Divisions of British Carboniferous Rocks as determined by their Fossil Flora,' *Proc. Roy. Phys. Soc. Edin.*, vol. xii, 1894, pp. 183-257.

1894 b ' On Some New Species of Fossil Plants from the Lower Carboniferous Rocks of Scotland,' *ibid.*, vol. xii, 1894, pp. 258-268.

1901 a ' Carboniferous Lycopods and Sphenophylls,' *Trans. Nat. Hist. Soc. Glasgow.*, vol. vi, 1901, pp. 25-140.

1902 d ' The Flora of the Carboniferous Period,' (Second Paper), *Proc. Yorks. Geol. and Polytech. Soc.*, vol. xiv, 1902, pp. 344-399.

1903 c ' List of Fossil Plants ' in ' Summary of Progress ' for 1902 (*Mem. Geol. Surv.*), 1903, pp. 130-137.

1903 d ' The Fossil Plants from the Canonbie Coalfield,' *ibid.*, 1903, pp. 209-216.

1903 e ' The Fossil Plants of the Carboniferous Rocks of Canonbie, Dumfriesshire and of parts of Cumberland and Northumberland,' *Trans. Roy. Soc. Edin.*, vol. xl, 1903, pp. 741-833.

1910 d ' List of Fossil Plants ' *in* ' The Geology of the Neighbourhood of Edinburgh,' (*Mem. Geol. Surv.*) 1910, pp. 384-388.

1915-1917 (with W. J. Jongmans) ' A Monograph of the Calamites of Western Europe ' *in* ' Flora of the Carboniferous of the Netherlands and Adjacent Regions ' by W. J. Jongmans, vol. i, *Meded. Rijksops. Delfstof.*, No. 7, Atlas, 1915, Text, 1917.

1916 b ' The Value of Fossils ' *in* ' The Economic Geology of the Central Coalfield of Scotland—Area V ' (*Mem. Geol. Surv.*), pp. 124-127.

1917 c ' The Forest of Wyre and the Titterstone Clee Hill Coalfields,' *Trans. Roy. Soc. Edin.*, vol. li, 1917, pp. 999-1084.

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VII.—THE MORVERN—STRONTIAN 'GRANITE'

BY

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Text-figures 1 and 2.

Introduction

FOR many years the existence of granite in the Strontian area at the head of Loch Sunart has been known, and a small granite boss appears at this locality on MacCulloch's Geological Map of Scotland, published by order of the Lords of the Treasury in 1840. The full extent of the mass, including the large portion in Morvern, is shown with approximate accuracy on the Geological Survey Map of the British Isles, on the scale of 25 miles to the inch, published in 1912.

During the survey of one-inch Sheet 53, Prof. E. B. Bailey mapped a small portion of the eastern edge of the Strontian 'Granite,' near Glen Tarbert. Farther to the south Mr. H. B. Maufe encountered what appeared to be the margin of a large granite mass, on the west shore of Loch Linnhe near Loch a'Choire. He suggested that it might eventually prove to be part of the Strontian mass.[1] Some years later Dr. G. W. Lee found that the south-easterly portion of Morvern, along Loch Linnhe, was occupied by the southerly extension of a very large granite mass, which he called the Morvern Granite.[2] More recently the Morvern—Stronian 'Granite' has been studied by Dr. J. F. Scott.[3] Lee and Scott recognized only two types of granite, and observed no junctions between them. Scott states[4] 'it is probable that they belong to one intrusion as no contact has been found and everywhere there is a gradual transition between them.'

During the summer of 1931 a large part of the granite area shown on Fig. 1 was surveyed. The two authors have been concerned with the northern part of the complex; the area westwards of Beinn Mheadhoin, and southwards into one-inch Sheet 44, was mapped by Mr. J. E. Richey, while the ground from Beinn Mheadhoin north-north-westwards to Liddesdale was mainly surveyed by Mr. R. C. B. Jones. The chief area not yet investigated in detail lies eastwards and north-eastwards from Beinn Mheadhoin.

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[1] Maufe, H. B., in 'The Geology of Ben Nevis and Glen Coe' (*Mem. Geol. Surv.*), 1916, p. 138.

[2] Lee, G. W., in 'The Pre-Tertiary Geology of Mull, etc.' (*Mem. Geol. Surv.*), 1925, pp. 45-47.

[3] Scott, J. F., 'General Geology and Physiography of Morvern, Argyll,' *Trans. Geol. Soc. Glasgow*, vol. xviii, Pt. I, 1928, pp. 154-157.

[4] Scott, J. F., *op. cit.*, p. 154.

In the present paper the results of the survey of the Morvern Granite-complex are co-ordinated by the authors with the evidence obtained by them north of Loch Sunart in 1930. Comparisons with certain other Scottish granites and injection-complexes are also made.

In the field season of 1931 it was found that the Morvern (or Strontian) ' Granite ' is a complex mass made up of three major intrusions of different granitic types with, almost everywhere, sharp mutual junctions. Furthermore the relations of the complex to the country rocks, and the similarity of the granites to other intrusions in the Highlands, indicate that the Morvern mass may provide a datum on which to base a time-scale for certain outstanding events in Highland geology.

Summary of Igneous and Metamorphic History

The portions of Morvern and Moidart within the limits of one-inch Sheet 52 and included in the scope of the present paper, possess a long and complicated igneous and metamorphic history. The country rocks consist of Moine Schists. These show a highly contrasted development on either side of an approximate line through Acharacle and Loch Arienas (about 8 miles west of Strontian). The western metamorphic facies includes pelitic, semi-pelitic and siliceous schists and granulites such as characterize the Moine Series in other parts of the Highlands. These rocks are intensely folded and show a dominant N.—S. strike and uniform high dip due to close-packed isoclinal folds.

The eastern facies is quite distinct and consists, to a large extent, of coarsely crystalline gneisses belonging to a great regional injection-complex the exact limits of which are, as yet, undetermined. The injection, however, increases in intensity from west to east, and north of Loch Sunart the complex passes out of Sheet 52, both in a northerly and easterly direction, with its general characters unchanged. These gneissic rocks have resulted from injection and permeation of a Moine host by granitic (pegmatitic) igneous material, and include many of the types described from the complexes of Central Sutherland.[1]

Prior to the folding and the regional metamorphism and injection, the Moine sediments were invaded by a series of thin sheets and dykes of basic igneous rock which, during the subsequent movements, became metamorphosed and drawn out into lenses of garnetiferous amphibolite. These are designated as ' Pre-injection Basic Rocks,' to distinguish them from another set of dominantly basic intrusions which cut the injection-gneisses and are therefore later than the regional injection. The later suite of intrusions forms sheets and subordinate dykes, individually thin but of enormous aggregate bulk, and includes fine-grained, often foliated, hornblende-lamprophyres together with

[1] Read, H. H., in ' The Geology of Central Sutherland ' (*Mem. Geol. Surv.*), 1931.

coarser-grained (sometimes very coarse) ultrabasic, basic and acid types. This diverse igneous assemblage is referred to collectively as the 'Appinite Suite,' typical members being identical with the appinites and related rocks of the Glen Coe district.[1] The group as a whole is characterized by the presence of quartz and alkali-felspar in rocks of all degrees of basicity. In the basic rocks the characteristic ferromagnesian minerals are green hornblende and pale pyroxene. A feature of considerable importance (p. 119) is the essential identity of this rock series with the 'Hybrid Rocks of Ach'uaine Type' described by Professor H. H. Read from Sutherland.[2]

It appears from the account in the Glen Coe Memoir[3] that there is general agreement among those who have worked on the Kentallenite-Appinite Suite of Argyllshire[4] that these rocks were intruded after the regional metamorphism, and are connected genetically as well as geographically with Caledonian granites. In Sunart and Morvern it has now been found that appinites are older than the Morvern Caledonian Granite-complex (pp. 114, 119). The mineralogical affinities of the appinites and members of the granite-complex are however so striking that it seems fairly certain that the Appinite Suite should be assigned to an early phase of the intrusive period of the younger or Caledonian granites.

Professor Bailey recognized that the hornblende-lamprophyre sheets of the Glen Coe district differ from appinites only in being finer-grained.[5] In Ardnamurchan, Moidart, and Sunart this also holds, but there is a certain amount of evidence to show that some of the lamprophyre sheets are older than some of the appinite intrusions. Since however these fine-grained and coarse-grained hornblendic intrusions are essentially identical in their constituent minerals, and since all are later than the regional metamorphism and the period of formation of injection-gneisses, they are assigned here to one general magmatic phase (Caledonian).[6]

As a point of general interest it may be mentioned that lamprophyres from Ardnamurchan and Moidart closely resemble some of the luciites and orbites of the Odenwald, in Germany.[7]

[1] Bailey, E. B., in 'The Geology of Ben Nevis and Glen Coe' (*Mem. Geol. Surv.*), 1916, pp. 167-168.

[2] Read, H. H., in 'The Geology of the Country around Golspie, Sutherlandshire' (*Mem. Geol. Surv.*), 1925, pp. 45-51: in 'The Geology of Strath Oykell, etc.' (*Mem. Geol. Surv.*), 1926, pp. 154-166: and 'The Geology of Central Sutherland' (*Mem. Geol. Surv.*), 1931, pp. 165-173.

[3] Bailey, E. B., and others in 'The Geology of Ben Nevis and Glen Coe' (*Mem. Geol. Surv.*), 1916, pp. 92, 139, 140, 155, 167, 168.

[4] Teall, Hill, Kynaston, Flett, Maufe, Bailey, Wright. See especially J. B. Hill and H. Kynaston, 'On Kentallenite and its Relations to other Igneous Rocks in Argyllshire,' *Quart. Journ. Geol. Soc.*, vol. lvi, 1900, pp. 531-557.

[5] Bailey, E. B., *op. cit.*, 1916, pp. 167, 177; cf. also J. B. Hill and H. Kynaston, *op. cit.*, 1900, pp. 548-551.

[6] Cf. Bailey, E. B., *op. cit.*, 1916, p. 140; and E. B. Bailey and W. B. Wright in 'The Geology of Colonsay, Oronsay, etc.' (*Mem. Geol. Surv.*), 1911, p. 36.

[7] MacGregor, A. G., in 'Summary of Progress,' for 1930, Part i (*Mem. Geol. Surv.*), 1931, p. 64.

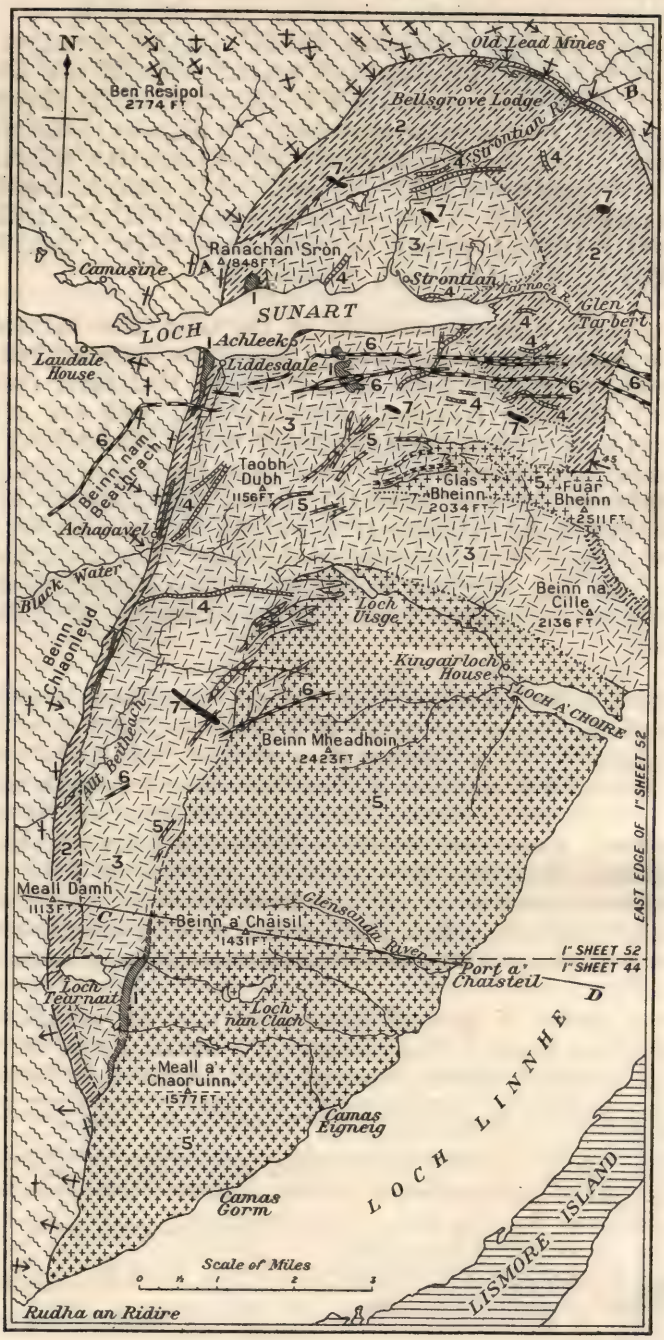

FIG. 1.—*Map of the Morvern—Strontian Granite-complex.*

The intrusion of the Appinite Suite was followed by the emplacement of the Morvern Granite-complex, of Caledonian age (p. 116), which is described below. The latter, in turn, is cut by minor intrusions, mostly dykes, of various types and ages.

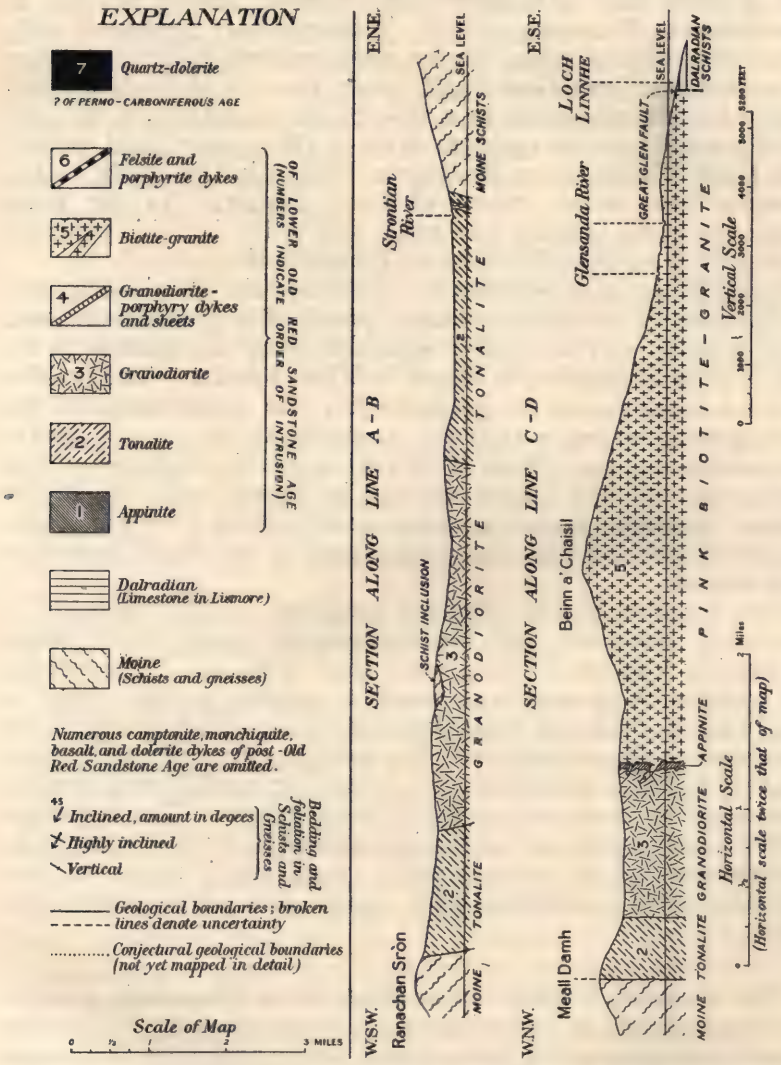

FIG. 2.—*Explanation of Fig.* 1, *and horizontal sections along the lines A-B and C-D.*

These include felsites and minettes of Old Red Sandstone type, dykes and elongated bosses of coarse quartz-dolerite, possibly belonging to the Permo-Carboniferous suite, and a great series of camptonite and monchiquite dykes of uncertain age. Finally the igneous history of the region terminated with the intrusion of Tertiary tholeiite and olivine-dolerite dykes.

The Morvern—Strontian 'Granite'

Small portions of the Morvern 'Granite' occur in one-inch Sheets 44 and 53, but the main outcrop occupies the south-easterly part of Sheet 52. Altogether the 'granite' covers an area of approximately 80 square miles. This evidently represents only part of the original mass, for the south-easterly portion has been cut out by the Great Glen Fault, along the line of Loch Linnhe.

The mass is elongated in a N.—S. direction (Fig. 1, p. 108), roughly parallel to the regional strike of the country, and extends from Loch Linnhe, near Rudha an Ridire, in the south, to the Strontian lead mines, north of Loch Sunart. In the latter district the width is about five and a half miles, but this increases southward to some eight miles at Kingairloch.

The different members now recognized in the granite-complex, are (in order of intrusion) tonalite, porphyritic granodiorite, and biotite-granite, and are readily separable from one another in the field. Their disposition is shown in Figs. 1 and 2. The tonalite forms an outer rim to the granodiorite; the main mass of the biotite-granite occurs within the granodiorite, but to the south-west, within one-inch Sheet 44, it cuts across the tonalite—granodiorite junction and comes directly in contact with the Moine Schists. Here the contact of granite and tonalite is well exposed; the granite cuts obliquely across the tonalite, and sends numerous veins into it.

The reaction of the different members of the complex to weathering processes, and the topographic forms which result, are striking features of the granite area[1] (Fig. 2). The tonalite and porphyritic granodiorite weather rapidly, partly owing to coarseness of grain and partly because of the susceptibility of the hornblende to decomposition. The tonalite—granodiorite country therefore forms a relatively low, grassy or peat-covered plateau surrounded by bare and rugged hills of gneiss. The resistance of the biotite-granite to weathering stands in marked contrast to the behaviour of the other granitic types, and it forms, in consequence, high mountains with steep, and often precipitous, slopes.

The Granitic Types.—In addition to the three main granitic types encountered as major intrusions within the complex, there is a fourth sub-type which forms broad sheets and dyke-like masses cutting the two earlier members. All four varieties possess certain features in common. These are notably, a richness in brown sphene which is obvious even in hand specimens, and a variable content of myrmekite.

The *Tonalite* is a medium- to coarse-grained, grey, biotite-hornblende-granodiorite, in which oligoclase is greatly in excess of orthoclase and microcline. Fluxional foliation is very well

[1] Cf. Scott, J. F., *op. cit.*, pp. 177, 182.

developed in the outer marginal zone but becomes vague towards the interior. A slice from the outer margin contains colourless diopside and brown biotite but no amphibole.

The *Porphyritic Granodiorite* is a coarse-grained, grey hornblende-biotite-granodiorite rather similar to the tonalite, from which, however, it differs in the presence of abundant, large porphyritic crystals of flesh-coloured perthitic orthoclase, up to one inch in length. Biotite is subordinate to hornblende. The felspar of the second generation is dominantly oligoclase, but the total amount of potash-felspar in the rock does not fall far behind that of soda-lime-felspar. The rock, therefore, approaches adamellite in composition.

The *Granodiorite-Porphyry* is a related type, forming sheets and dykes. It differs from the above mainly in the larger size of the phenocrysts, which may attain a length of three inches, and in the finer-grained and more quartzose nature of the groundmass. The latter also contains a slightly greater proportion of orthoclase and microcline.

The *Biotite-Granite* is fine-grained, pink in colour, and with more quartz than any of the other types. Potash-felspar, including both orthoclase and microcline, is greatly in excess of oligoclase, and biotite is the sole ferromagnesian mineral. Normally the rock is porphyritic with two generations of orthoclase and microcline, the earlier forming small, flesh-coloured phenocrysts up to half an inch in length. Sphene is present but is not so abundant as in the other types.

The Granite Junctions.—The schists and gneisses, at the immediate contact of the tonalite, exhibit certain unusual characters, a description of which is deferred to a later section (p. 115). The tonalite—schist junction is essentially vertical between Loch Linnhe and Loch Sunart. North of Loch Sunart, however, it is inclined centrally at an angle of about 70°. In Glen Tarbert verticality is once more attained, but when traced southward the junction-plane dips inwards at an angle of 45° or less. South of Fuar Bheinn the relations are complicated by the obliteration of parts of the contact by massive sheets and dykes of fine-grained pink biotite-granite.

Lens-shaped basic enclaves are found in all members of the granitic complex. In the tonalite they are abundant, and are orientated parallel to its foliation, which conforms to the trend of the tonalite—schist contact. Locally the marginal zone of tonalite is riddled with acid veins, including cream-coloured aplites, aplo-pegmatites and pegmatites, which vary in width from less than one inch up to three or four feet. These maintain no constant direction but form a network of intersecting veins which cut across the foliation of the tonalite and themselves show no directional structures.

The tonalite—granodiorite junction, which runs approximately parallel to the outer contact of the granitic complex, forms a definite mappable line along the western side of the mass. The actual junction is often difficult to locate as it tends to form a hollow feature, but at numerous points it can be demonstrated that the change from granodiorite to tonalite takes place within a few inches. In a number of places the granodiorite shows a narrow, fine-grained and somewhat more basic marginal phase against coarse unmodified tonalite, and the line of contact cuts obliquely across the foliation of the tonalite. This evidence points to a later age for the granodiorite. At one locality the two intrusions are separated by a line of crush later than both.

For some distance along the north-east side of the granodiorite, north of Glen Tarbert, a sharp contact is no longer obvious and the separation of the two types in the field becomes a matter of great difficulty. This results partly from the badly exposed nature of the ground and partly from a similarity between the two intrusions in this region. There is a marked decrease, both in size and abundance, of the pink phenocrysts in the granodiorite, which thereby comes to resemble the tonalite. At the same time, the tonalite, even away from its outer margin, possesses a rude foliation never seen in the granodiorite and, further, it is somewhat richer in biotite. These characters permit the drawing of an approximate line. In the poorly exposed ground between the Loch Sunart—Glen Tarbert valley and the granite intrusion of Fuar Bheinn, there appears to be a transition between the tonalite and the granodiorite. Further work, may, however, result in the mapping of a line of separation more definite than that indicated provisionally in Fig.1. Evidence as to the form of the tonalite—granodiorite contact-surface is hard to obtain owing to low topographic relief. North of Loch Sunart there is evidence of a central inclination of the junction as in the case of the tonalite—schist contact but elsewhere it appears to be vertical (e.g., south of Loch Tearnait, on fairly steep slopes).

Irregular sheets and dykes of granodiorite-porphyry cut the tonalite and granodiorite, especially in the Loch Sunart district. They are older than the east—west felsite dykes. From their similarity to the granodiorite it is probable that these sheets and dykes are only slightly younger than the main mass of granodiorite, and are older than the intrusions of pink biotite-grainite. Conclusive evidence on the latter point has, however, not yet been obtained.

Junctions of pink biotite-granite with granodiorite or tonalite are always sharp and clean-cut; nowhere is there any suggestion of a transition. The western margin of the granite, as far north as a point west of Beinn Mheadhoin, is simple and well-defined. Farther north the margin becomes exceedingly complex. Everywhere the junctions are either vertical or steeply inclined.

Towards the south end of its western margin, east of Loch Tearnait, the pink biotite-granite is separated from the granodiorite by a narrow, vertical, strip of fine-grained appinitic rock, some two miles in length and from one to two hundred yards in width. This is veined by both intrusions.

To the north, in the neighbourhood of Loch Uisge, the granite fringes out into a complex of broad, irregular branching sheets and dykes which cut tonalite, granodiorite and Moine Schists. Many dykes and sheets show no visible connection with the main outcrop but continuity in depth may be postulated.

East and north of Beinn na Cille a preliminary traverse shows that the schists, the tonalite and the granodiorite, are cut by numerous sheets of pink biotite-granite which largely obliterate the earlier plutonic junctions. The ground between the Glas Bheinn —Fuar Bheinn ridge and the Loch Uisge—Loch a' Choire valley has not yet been mapped in detail; it is probable that anastomosing sheets of granite will be found cutting the granodiorite in this area.

In one-inch Sheet 53 a considerable extension of the Morvern 'Granite,' forming the great spur of Druim na Maodalaich, was mapped by Mr. Maufe along the western shore of Loch Linnhe, just to the north-east of Loch a'Choire. A traverse across part of this intrusion has now shown that it is a complex, consisting of granodiorite cut by numerous sheets of pink biotite-granite.

Inclusions in the Granitic Complex.—The various members of the complex contain abundant inclusions which vary in size from less than one inch up to hundreds of yards. These include injection-gneisses and schists in addition to several types of igneous rock exhibiting a more or less pronounced consanguinity with the granitic complex.

Inclusions of schists and gneiss are rather abundant to the north of Loch Sunart and the main occurrences are indicated on the sketch-map (Fig. 1, p. 108). The largest mass measures five hundred yards by about three hundred, but numerous blocks up to about one hundred yards are known. Both injection-gneisses and siliceous granulites are represented, and commonly they are much veined and permeated by granitic material from the enclosing granites. Strikes and dips are very contorted and it is impossible to determine the attitude of these blocks in relation to the schists of the outer contact. They are possibly sunken blocks, for they may occur 500 to 600 feet below the level of the outer contact.

Along the extreme northern margin of the complex a continuous strip of siliceous granulite, 20 yards in width, has been mapped for a distance of two miles, and throughout this distance it maintains a parallelism with the tonalite—schist contact-surface both in strike and dip, even where the outcrop of the latter shows

minor bends and indentations. This granulite inclusion probably originated through the stoping off of a thin sheet of country rock along an arcuate fracture line.

Igneous Inclusions.—These rocks are predominantly basic, hornblendic types, belonging to the Appinite-Lamprophyre Suite and although several distinct varieties can be recognized, it is obvious that a close genetic relationship exists between them. They all show a marked richness in brown sphene, as in the case of the granitic rocks.

The larger masses, indicated on Fig. 1, consist of coarse-grained basic appinite. The xenolithic nature is clearly seen at several localities but especially on the south shore of Loch Sunart near Achleek, where a large mass of appinite is cut by veins from the surrounding granodiorite. Small xenoliths have also been stoped off the basic inclusion and lie embedded in granodiorite close to the edge of the appinite mass. Thus the appinites are undoubtedly earlier than the granite-complex, and are not intrusive into it as suggested by Scott after his examination of the Loch Sunart occurrences.[1]

Locally both appinite and surrounding granite have suffered more or less intense modification where they come into contact. This consists of basification of the granite together with acidification of the appinite, and gives rise to various hybrid types. In other places the junctions are clean-cut. Another peculiarity of the appinite enclosures is the local presence of large well-formed plagioclase-felspars which are, so far, unknown in appinites not enclosed in the granitic rocks (p. 107).

Some of these basic appinite inclusions exceed in size any intrusions of appinite at present known in the district. This makes it probable that they represent parts of a large intrusion, belonging to an early period in the history of the complex, stoped off by the ascending granitic magma.

In various parts of the complex there are elongated dyke-like or sheet-like masses of fine-grained, pale to dark grey rocks, of dioritic composition. In some cases, in well-exposed ground, their xenolithic nature is unmistakable. Without careful observation, however, these rocks may easily be taken for minor intrusions cutting the granodiorite, and in certain instances their real nature is not yet settled.

Both the tonalite and granodiorite, and to a lesser extent, the biotite-granite, contain abundant small, lens-shaped basic enclaves, greyish in colour and very rich in sphene. They are characterized by numerous large well-formed crystals of plagioclase which, in some cases at least, are of the nature of porphyroblasts, as in many instances they have been developed across the junction of xenolith and granite.

Stages in the formation of these cognate enclaves have been observed in numerous localities. The phenomena closely resemble

[1] Scott, J. F., *op. cit.*, 1928, p. 155.

those described by Thomas and Campbell Smith from Brittany.[1] Large blocks of enclave material are seen to be dissected by permeating granite veins into a series of small lenses which are in process of being floated off and dispersed through the main granitic mass. The lens shape is therefore an original feature of the small xenoliths. Slight foliation in the basic rock has mainly guided the granite veins, and for this reason the directional structure is parallel to the long axis of the enclave.

The Schists at the Granite-contact.—The manner in which the schists and gneisses have reacted to the intrusion of the Morvern ' Granite ' imparts to the complex a distinct individuality and affords evidence both of the mode of intrusion and the physical conditions prevailing at the time of emplacement.

Considered as a whole the granite-complex is definitely transgressive to the country rocks, as characteristic bands in the latter may be traced up to the granite contact and may be seen to terminate against it. At the same time, where the country rocks have a regional strike nearly normal to the granite margin they have been swung round into conformity and now strike parallel to the outer margin of the complex (e.g., north of Strontian). Further, it is found that at the contact the dip of the schists and gneisses is parallel to the walls of the complex and to the foliation in the tonalite.

That these concordant relations are due to flowage of the country rocks under the influence of magma pressure, can be demonstrated at various points along the margin, especially in the neighbourhood of Bellsgrove Lodge and on the shores of Loch Sunart. In these localities the complex is in contact with pelitic injection-gneisses containing bands of siliceous granulite and of amphibolite. Pronounced disruption and de-orientation have resulted in the formation of ' breccias ' consisting of angular blocks of siliceous or hornblendic rocks embedded in a matrix of injection-gneiss. The pressure of the intruding granite has forced the country rocks aside : the pelitic types have yielded by flowage, but the more resistant siliceous and hornblendic varieties have been broken into angular blocks round which the foliation of the pelitic matrix bends.

The actual outer line of contact is sharp and, although the tonalite sends a few veins into the country rocks, there is no general fading out of granite into a zone of injection. *The granite definitely cuts the injection-gneisses.*

The schists and gneisses in contact with the granitic mass show little or no trace of contact-alteration. This might be expected in the case of siliceous granulites, for they would not readily reveal the effects of later thermal metamorphism superimposed on earlier regional alteration. The pelitic types on the other hand would

[1] Thomas, H. H., and W. Campbell Smith, *Quart. Journ. Geol. Soc.*, vol. lxxxviii, 1932, p. 274-296 (especially pp. 279-281).

not normally have failed to show contact-metamorphism had the granite exerted any marked thermal effect on its wall rocks.[1]

We must conclude therefore that, as the Morvern ' Granite ' shows neither an injecting nor a hornfels type of contact, the physical conditions prevailing during intrusion must have been abnormal.

Age and Affinities of the Morvern—Strontian ' Granite '

The Morvern—Strontian ' Granite ' does not cut any stratified rocks younger than the Moine Series. A possible upper limit to its age is however afforded by the outlier of breccia and red sandstone at Rudha na Earba on the shore of Loch Linnhe.[2] These sediments, believed by Peach to be of Middle Old Red Sandstone age, rest upon granite which is possibly a downfaulted portion of the Morvern mass.[3] This would indicate a post-Moine and pre-Middle Old Red Sandstone age for the intrusion. The main arguments that have been advanced in support of a Lower Old Red Sandstone age are :—(1) The Morvern—Strontian ' Granite ' is subsequent to the regional movements and metamorphism of the Moine Series, and (2) it shows close petrological affinities with other granites of proved Lower Old Red Sandstone age.[4] In addition we know that the mass is subsequent to the regional injection of the Morvern—Moidart region and to the intrusion of the Appinite Suite (p. 114), and that it is cut by minor intrusions of Lower Old Red Sandstone type.

The problem is one which concerns not only the Morvern ' Granite ' but also several of the so-called Younger or Caledonian Granites north and south of the Great Glen. These may be considered here as well, and in the Table on p. 117 an attempt is made to summarize the salient features of the Morvern—Strontian, Etive (Cruachan and Starav),[5] Ben Nevis,[6] Moor of Rannoch,[7] Glenelg—Ràtagain,[8] and Lairg—Rogart[9] granite-complexes.

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[1] In Glen Clova and Glen Doll injection-gneisses have been intensely hornfelsed by a later granite (A. G. MacGregor, ' Metamorphism around the Lochnagar Granite, Aberdeenshire,' *Rep. British Assoc., Glasgow*, 1928, pp. 553-554).

[2] This locality does not lie within Fig. 1.

[3] Bailey, E. B., in ' The Geology of Ben Nevis and Glen Coe ' (*Mem. Geol. Surv.*), 1916, p. 211. J. F. Scott, *Trans. Geol. Soc. Glasgow*, vol. xviii, Pt. i, 1928, p. 156.

[4] Bailey, E. B., in ' The Pre-Tertiary Geology of Mull, etc.' (*Mem. Geol. Surv.*), 1925, p. 45 ; also E. B. Bailey, *op. cit.*, 1916, pp. 91-92.

[5] Kynaston, H., in ' The Geology of the Country near Oban and Dalmally ' (*Mem. Geol. Surv.*), 1908, pp. 82-91. C. T. Clough and others in ' The Geology of Ben Nevis and Glen Coe ' (*Mem. Geol. Surv.*), 1916, pp. 119-127 ; 150-168.

[6] Maufe, H. B., ' Summary of Progress ' for 1909 (*Mem. Geol. Surv.*), 1910, pp. 80-89. Also Glen Coe Memoir, pp. 128-134, 150-168.

[7] Bailey, E. B., and others in ' The Geology of Ben Nevis and Glen Coe ' (*Mem. Geol. Surv.*), 1916, p. 135 and pp. 150-168. Also L. W. Hinxman and others in ' The Geology of Corrour and the Moor of Rannoch ' (*Mem. Geol. Surv.*), 1923, pp. 62-71.

[8] Clough, C. T., in ' The Geology of Glenelg etc. ' (*Mem. Geol. Surv.*,), 1910, pp. 84-88.

[9] Read, H. H., in ' The Geology of Strath Oykell, etc.' (*Mem. Geol. Surv.*), 1926, pp. 148-154, also ' The Geology of the Country around Golspie ' (*Mem. Geol. Surv.*), 1925, pp. 21-36.

SUMMARY OF MAIN CHARACTERS OF CERTAIN 'YOUNGER' (CALEDONIAN) GRANITE-COMPLEXES

×, Recorded; —, Not recorded; ?, Information indefinite; +, Present, but not previously recorded.

	Characteristics of Complex	Morvern-Strontian	Etive (Cruachan and Starav)	Ben Nevis	Moor of Rannoch	Glenelg-Ràtagain	Lairg-Rogart
	Complex mass with two or more granitic types	×	×	×	×	×	×
Rock Types	Grey tonalite	×	×	×	×	×	×
Rock Types	Porphyritic granodiorite, with pink orthoclase phenocrysts	×	×	×	×	?	×
Rock Types	Quartzose pink biotite-granite or adamellite, poor in ferro-magnesian minerals	×	×	×	×	×	×
	Granite, or adamellite, is youngest member of complex	×	×	×	×	×	?
	Sharp (intrusive) junctions between some or all of members of complex	×	×	×	—	×	—
	Apparent transitions between granite and granodiorite or tonalite	none	local only	—	×	?	?
	Well-marked fluxional foliation in tonalite	×	×	—	×	×	×
	Tonalite contains many flat basic enclaves (cognate), orientated with their long axes parallel to foliation	× (sphene-rich)	×	—	× (sphene-rich)	×	× (sphene-rich)
	Brown sphene abundant in granodiorite and tonalite	×	×	×	×	—	×
	Large masses of coarse basic hornblende-pyroxene rocks * cut by, or enclosed in, complex... ...	×	×	?	—	×	×
	Myrmekite developed in granites and granodiorites	×	+	—	×	—	×

*In the west of Scotland, these are basic members of the Appinite Suite. In the Lairg-Rogart complex they are called 'Hybrid Rocks of Ach'uaine Type.'

Comparison of hand specimens and petrographic descriptions of rocks from the various masses reveals a striking similarity between them, and in many cases the rocks are identical. For this reason and on account of the above evidence it is most probable that they belong to a co-magmatic province. Certain of them, such as Ben Nevis and the Etive complex, are definitely proved to be of Lower Old Red Sandstone age.[1] The Moor of Rannoch Granite,[2] on the other hand, is older than the Cruachan

[1] Bailey, E. B., and others in 'The Geology of Ben Nevis and Glen Coe' (*Mem. Geol. Surv.*), 1916, pp. 91, 92.

[2] Bailey, E. B., and others, *op. cit.*, pp. 91, 92; also L. W. Hinxman, in 'The Geology of Corrour and the Moor of Rannoch' (*Mem. Geol. Surv.*), 1923, p. 62.

mass and so it is probable that the period of intrusion extended over an interval of time greater than that represented by the successive intrusions within each mass. For this reason it is preferable to refer this suite of Younger (post-regional-metamorphism) Granites, as a whole, to a ' Caledonian ' age rather than to restrict them to a Lower Old Red Sandstone age.

Professor Read, in the later of his two official accounts of the Lairg—Rogart granodiorite[1] assigned the intrusion to the ' Newer ' or ' Younger ' (post-regional-metamorphism) granites of Scotland.

The Lairg—Rogart granodiorite is characterized by the granite-granulite 'injection-complex ' which it has formed with the Moine Schists along the margin.[2] By 1931 Professor Read, influenced partly by the proximity of this injection-zone to the southern edge of the Loch Choire Injection-complex of Central Sutherland, had been led to the view that the intrusion of the Lairg—Rogart granodiorite was contemporaneous with the intrusion of the granitic material of the Loch Choire Injection-complex, and was pre-Torridonian in age.[3]

The following facts may however be cited in further support of the view that the Lairg—Rogart granodiorite is of ' Newer Granite,' or Caledonian age, and is not contemporaneous with the formation of the Loch Choire Injection-complex:

(1) Mr. H. Kynaston has given a clear description of an ' injection-complex ' produced by the Cruachan granite (of proved Lower Old Red Sandstone age) along part of its margin;[4] and this description agrees in detail with Professor Read's account of the Lairg—Rogart zone of injection.

(2) It would appear from the descriptions that the Lairg—Rogart injection phenomena differ very considerably from those of the Loch Choire complex.[5]

(3) Professor Read has himself pointed out that the injection-complexes of Rogart and Loch Choire are structurally quite different.[6]

We may now summarize Professor Read's Sutherland time-sequence[7]—in its latest form (1931)—for the Hybrid Rocks of Ach'uaine Type, the period of regional granitic injection, and the intrusion of the Lairg—Rogart granodiorite:—

(1) Intrusion of ultrabasic hornblende-pyroxene rocks or of ultrabasic magma.[8]

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[1] Read, H. H., in ' The Geology of Strath Oykell, etc.' (*Mem. Geol. Surv.*), 1926, pp. 9, 148.
[2] Read, H. H., in ' The Geology of the Country around Golspie, Sutherlandshire ' (*Mem. Geol. Surv.*), 1925, pp. 21-40; and H. H. Read, *op. cit.*, 1926, p. 151.
[3] Read, H. H., ' The Geology of Central Sutherland ' (*Mem. Geol. Surv.*), 1931, p. 194.
[4] Kynaston, H., in ' The Geology of the Country around Oban and Dalmally ' (*Mem. Geol. Surv.*), 1908, pp. 82-84.
[5] Read, H. H., *op. cit.*, 1931, pp. 90, 146, etc.
[6] Read, H. H., *op. cit.*, p. 146.
[7] Read, H. H., *op. cit.*, 1925, pp. 5, 21, 34, 45-51; and *op. cit.*, 1926, pp. 8-9, 112-118, 148-152, 154-156, 165; and *op. cit.*, 1931, pp. 11-13, 140, 146, 151, 153, 162, 165, 169, 173, 178, 188, 189, 193, 194.
[8] Prof. Read is undecided as to whether the ultrabasic intrusions had consolidated before the regional acid injection of phase (2) took place. Read, H.H., *op. cit.*, 1931, pp. 12, 165-173.

(2) Pre-Torridonian regional injection of Moine Schists by acid pegmatitic and granitic magma, locally derived from the Lairg—Rogart granodiorite. Production of ' Hybrids of Ach 'uaine Type ' where the injecting acid magma encountered intrusions of ultrabasic rock or ultrabasic magma.

(3) Shearing of ultrabasic hornblende-pyroxene rocks (and of locally uninjected Moine Schists in which they are intruded) by post-Cambrian movements connected with the Moine Thrust.

In the Morvern—Sunart—Moidart district, as we have seen, there is a very similar set of rocks. The close resemblance between the Lairg—Rogart and Morvern—Strontian ' Granites ' has already been emphasized. In connection with the associated basic hornblendic rocks it may be stated that there are few, if any, of the Survey hand-specimens of the ' Ach'uaine Hybrids ' of Sutherland, that cannot be exactly matched by specimens of the Appinite-Lamprophyre Suite from Morvern, Sunart, and Moidart. Moreover, many of the latter group of intrusions, showing characteristic late acid veining and permeation (auto-hybridization), are found either cutting the gneisses formed by regional acid injection, or beyond the limits of this injection. Foliation, in some cases due to fluxion and in others to post-consolidation shearing, is often observed. The time-sequence determined by the authors is as follows :—[1]

(1) Regional injection of acid pegmatitic magma.

(2) Intrusion of ultrabasic to acid igneous rocks (Appinite-Lamprophyre Suite).

(3) Intrusion of Morvern—Strontian 'Granite,' of Caledonian, probably Lower Old Red Sandstone, age.

Professor Read regards his conclusions in Sutherland as tentative—a first attempt at the solution of a complex and difficult problem. Future workers should, therefore, bear in mind the following suggestions, based on the comparison of Sutherland with western Scotland :—(1) Some, at least, of the Hybrids of Ach'uaine Type may be of Caledonian age, and unconnected with any regional injection phenomena. (2) In Sutherland there may be injection-rocks of different ages, the latest belonging to a localized area of injection produced around the Lairg—Rogart granodiorite of Caledonian (probably Lower Old Red Sandstone) age.

[1] It seems reasonable to conclude from Dr. C. T. Clough's description in the Glenelg Memoir (footnote, p. 116 *supra*) that a similar suite of igneous and metamorphic rocks, with the same time-sequence, occurs in the Glenelg—Ràtagain district.

VIII.—NOTE ON *RETICULOCERAS RETICULATUM* (PHILLIPS), LATE MUT. β BISAT

BY

W. S. BISAT, F.G.S.

1924. *Reticuloceras reticulatum* (Phillips), mut. β Bisat, *pars*. *Proc. Yorks. Geol. Soc.*, vol. xx, p. 117, pl. vii, fig. 2.

UNDER the original description of *R. reticulatum*, mut. β were included two forms.[1] The earlier form, which occurs under the 3rd Grit of Pule Hill, Yorkshire, and is believed to be Salter's *Goniatites bilinguis*, is relatively strongly ornamented and with a marked serpenticone early adolescent stage (see Pl. iii, figs. 7, 8, and Pl. vii, figs. 3, 4, *op. cit.*). Its ribbed early ornamentation persists on the umbilical area into adolescence, where strong short plications are seen bordering the umbilicus (Pl. iii, fig. 9, *op. cit.*).

In the later form (late mut. β), which occurs above a grit band correlated with the Readycon Dean series of Lancashire,[2] the ornament is much weaker than in typical mut. β, and the umbilical plications are reduced in strength to ordinary striae, except that on the internal cast in adolescence obtuse plications are visible. The serpenticone stage is reduced and the umbilicus in early adolescence is smaller. The transverse striae are somewhat closer than in typical mut. β and average about 5 to the mm. on the lingua at 18 to 20 mm. diameter, with some specimens ranging up to 7 to the mm. On the test the transverse striae tend to be weakly crenulate, the spirals on the flanks are weak, and on external moulds may appear to be absent except on the lingua.

Late mut. β is widely spread in Yorkshire, and occurs both crushed in shale and in small nodules about the size of walnuts, in which the specimens are usually preserved in the form of moulds of the external test. In 1924 I referred to this band as the nodular β band, and the earlier band with typical mut. β as the β plus *proteum* band,[3] and stated that no definite stratigraphical correlation of the two had then been made.

The subsequent work of the Geological Survey, especially in the collecting of specimens from borings near Huddersfield,[4] seemed to confirm the assumption one would make on palaeontological grounds, that the nodular β or late β bed was higher than the β plus *proteum* band, but has left the details of the faunal stratigraphy in a not quite completely satisfactory state.

[1] 'The Carboniferous Goniatites of the North of England and their Zones,' *Proc. Yorks. Geol. Soc.*, vol. xx, 1924, p. 117, pl. vii, figs. 1-4; pl. iii, figs. 7-9.
[2] 'The Country around Huddersfield and Halifax' (*Mem. Geol. Surv.*), 1930, p. 38.
[3] *Op. cit.*, 1924, p. 61.
[4] 'The Country around Huddersfield and Halifax' (*Mem. Geol. Surv.*), 1930, pp. 189-192.

The holotype is a shale impression collected from Wakefield Waterworks Tunnel, Ripponden Edge, Barkisland, Yorkshire, and numbered 50265; paratypes are specimens 50266-8, of which two are internal casts, all from the above described locality, and also two external moulds numbered 50270, 50271, from an old quarry on the east side of Varley Road and 150 yds. E.N.E. of Mansergh House, Slaithwaite. I have presented all these types to the Museum of Practical Geology. A further paratype is the specimen figured in my paper of 1924 (*op. cit.*), pl. vii, fig. 2, from 725 ft. O.D., Pike Clough, Rishworth, Halifax. This specimen is preserved in the British Museum (Natural History) and bears the register-number C.25760.

IX.—THE NATURE AND AFFINITIES OF *PALAEOXYRIS*, ETC.

BY

R. CROOKALL, D.Sc., PH.D.

Plate II.

INTRODUCTION

FEW organic remains have been the subject of such diverse speculation as have those of *Palaeoxyris* and its related genera, *Vetacapsula* and *Fayolia*.[1,2] It is unnecessary here to review in detail the groups to which they have been referred and the plants and animals with which they have been compared: while some of the most eminent palaeontologists (e.g., L. Lesquereux, D. White, C. Grand'Eury and A. C. Seward) would commit themselves to no definite conclusion, various forms included in the genera have been considered to represent or have been compared with

(1) flower-buds, inflorescences and fruits of various plants.
(2) stems of algae,
(3) tubers, buds, bulbils and abnormal stems of *Calamites*,
(4) rhizomes of *Cordaites* with spirally unfolding leaves,
(5) ' seed-vessels ' of *Sigillaria*,
(6) the fruits of an East Indian species of Mangrove (the Bakao),
(7) envelopes formed by insects for enclosing their larvae,
(8) galls,
(9) relatives of the ' Stoneworts ' (Charaphyta),
(10) sponges,
(11) coprolites,
(12) egg-cases of various groups of fishes.

Other comparisons could have been drawn. It may be pointed out, for instance, that *Vetacapsula* shows a great resemblance in body, beak and pedicle to the fruit of *Terminalia sp.*, an African member of the Combretaceae. This fruit, measuring about 9 cm. in total length, has, however, a membranaceous wing 10 or 12 mm. in width.

While the most favoured theory is that they represent the egg-cases of fishes, this has not hitherto received general acceptance

[1] Recently, an allied form, *Scapellites*, has been described by Professor P. Pruvost (*Ann. de la Société scientifique de Bruxelles*, Tome xlii, 1922, pt. i, Documents et Comptes rendus, pp. 150-3, pl., figs. 1-4).

[2] There is some question as to whether the generic name *Spiraxis* should not have priority over Renault and Zeiller's *Fayolia*. The genus *Spiraxis* was described in a paper read on Dec. 10th, 1883. That describing *Fayolia* was read on June 2nd, 1884. There is a slight doubt as to which description was first *published*, but *Fayolia* was published in 1884, whereas, according to Zeiller (*Études sur le terrain houiller de Commentry*, St. Etienne, 1880-1890, pt. i, p. 15), *Spiraxis* was not published until 1885.

among those most competent to judge.[1] The view, first developed in 1888 by Renault and Zeiller,[2] was adopted in 1910 by Moysey[3] and later by Professor P. Pruvost.[4]

As the writer,[5] in order to identify fossils found during the revision of the South Wales Coalfield, recently undertook a morphological survey of the genera, it has been thought desirable to place on record the observations made as to the construction and nature of the organisms.

The Construction of the Organisms

Three views have been advanced as to the original construction of *Palaeoxyris, Vetacapsula* and *Fayolia*. As a rule, these opinions have been expressed with regard to *Palaeoxyris* only, but genera so closely related must be considered together.

A. Schimper's View

Early writers (e.g., Schimper) regarded *Palaeoxyris* as a capsule composed of a number of narrow leaves (? or carpels) united by their margins. The component leaves were supposed to become twisted as the capsule matured. This type of construction was suggested by the superficial resemblance of the fossils to the fruits of certain recent plants. Now, in *Vetacapsula* the segments are typically straight, and this feature is correlated with the presence of a longitudinal median flange[6]: in *Palaeoxyris* and *Fayolia,* on the other hand, there is no median flange and the segments are invariably twisted. In the latter two genera the spiral arrangement must be regarded as a normal condition and independent of the maturity of the capsule, otherwise one would expect to find small, immature, forms with straight segments as well as forms intermediate between these and those with normal spirals. *Vetacapsula* cannot be regarded as such intermediate forms, for they exhibit constant differences from *Palaeoxyris* and *Fayolia,* as has been shown by the writer.[7]

[1] See, for instance, Dr. Smith Woodward's observations in the discussion following the late Dr. L. Moysey's paper 'On *Palaeoxyris* and other Allied Fossils from the Derbyshire and Nottinghamshire Coalfield,' *Quart. Journ. Geol. Soc.*, vol. lxvi, 1910, p. 344—Dr. Smith Woodward 'regretted that the new facts appeared still to leave the true nature of these organisms in doubt.'

[2] Renault, B., and R. Zeiller, 'Sur l' attribution des genres *Fayolia* et *Palaeoxyris*,' *Compt. rendus*, vol. cvii, 1888, p. 1022.

[3] Moysey, L., *op. cit.*, 1910.

[4] Pruvost, P., 'La Faune continentale du terrain houiller du nord de la France,' *Mém. Carte Géol. Dét. de la France*, 1919, pp. 445-446.

[5] Crookall, R., 'Palaeozoic Species of *Vetacapsula* and *Palaeoxyris*,' 'Summary of Progress' for 1927, Pt. ii (*Mem. Geol. Surv.*), 1928, pp. 87-107; 'The Genus *Fayolia*,' *The Naturalist*, 1928, p. 325; 'Further Morphological Studies in *Palaeoxyris*, etc.,' 'Summary of Progress,' for 1929, Part iii (*Mem. Geol. Surv.*), 1930, pp. 8-36.

[6] In some of the smaller species of *Vetacapsula* the median flange is absent and the segments tend to have a slight local twist. It may be necessary to separate these under a distinct generic name (see R. Crookall, *op. cit.*, 1930, p. 28).

[7] Crookall, R., *op. cit.*, 1928, p. 90.

B. Nathorst's View

In 1879 Nathorst[1] suggested that *Palaeoxyris* was produced by the lateral union of spirally arranged tubes, a construction which was correlated with his suggestion that the organisms were related to the Characeae (' stoneworts '). This interesting view has received no comment from subsequent authors apart from a brief note by Zittel.[2] Nathorst arrived at his suggestion as follows: from the fact that *Palaeoxyris* is almost invariably associated with plant remains, he assumed that the organisms were plants; from their remarkable stability through an exceptionally long period of geological time, that they were probably aquatic plants. He compared the fossils with the ' fruits ' of the recent *Chara* and was inclined to regard them as members of the Characeae.

Nathorst observed that, in certain of his specimens, there are lines which continue from the spiral ribs, following the same direction, into the matrix surrounding the fossil. He suggested that this feature is present in the specimen he figured on his Plate vi, fig. 1 (*Palaeoxyris* cf. *münsteri* from the Lower Lias of Scania), but a comparison of the specimen with the figure shows that the artist has exaggerated the markings.[3] The counterpart of the fossil (which was not figured) shows, on the left-hand side (and therefore corresponding to the right-hand side of the figured specimen), similar and more obvious lines which are clearly due to the sharply pointed ribs of the organism.

Nathorst further pointed out that lines similar to those he stressed as continuing from the ribs into the matrix of some of his specimens are to be observed in certain of Ettingshausen's figures of *Spirangium jugleri*, but an inspection of the drawings in question reveals nothing favouring their interpretation as spirally arranged tubes.[4]

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[1] Nathorst, A. G., ' Om *Spirangium* och dess *Förekomst*, I, Skånes Kolförande Bildningar,' *Sveriges Geologiska Undersökning*, Ser. C, No. 36, 1879. (I have to thank Dr. R. Florin, of Stockholm, for providing me with a résumé of this paper).

[2] Zittel, K. A., Traité de Paléontologie, part ii, Paleophytologie, 1891, p. 382 (trans. C. Barrois).

[3] In the figure, especially on the left, several very definite lines are depicted as continuing directly from the ribs into the matrix. In the specimen there is a suggestion of such lines, but they are less numerous, less regular and less clearly marked than would be gathered from an examination of the figure.

Through the kindness of Professor T. G. Halle, of the Naturhistorika Riksmuseets, Stockholm, Sweden, I have had the advantage of examining, among others, the specimens of *Spiranguim* described and figured by Nathorst. This with the unfortunate exception of a most important fossil from Sofiero—Nathorst's Pl. vii, fig. 5, which could not be traced. According tc Nathorst's Explanation of Plates, it belonged to the collection of the Swedish Geological Survey.

[4] It has not been possible to borrow Ettingshausen's original specimens for comparison with his drawings, but a careful examination of a large number of specimens of the same species coming from the same locality and preserved in the British and various foreign Museums, confirms the view expressed above.

Although Nathorst's drawings exaggerate the evidence[1] on which he based his view as to the tubular construction of *Palaeoxyris*, apart from his specimens, examples suggestive of a tubular construction of the fossils are not wanting. The following may be cited :—

(1) Specimens of *P. helicteroides* in the Manchester Museum numbered L.1368, W.1183, L.1370 ;

(2) *Fayolia dentata* as figured by Renault and Zeiller[2] ;

(3) the specimen of *Fayolia randalli* figured by the writer in 1930[3] ;

(4) The part and counterpart of a specimen of *S. jugleri*[4] from the Fairlight Clays (Wealden) of Ecclesbourne, near Hastings, suggests a tubular construction. The two halves of this specimen, which is about three inches long, were fortunately preserved, showing both mould and cast. The beak is present, but the pedicle is not preserved. The fossil appears to support Nathorst's contention as there are four or five flattened tubular projections overlapping the internal cast. Individually, these are 5 or 6 mm. long (i.e., across the width of the segments) and rather more than 2 mm. thick.

Occasionally, as in the present instance, more than one partial view of the fossil may be presented.[5]

The following facts are against Nathorst's suggestion as to the construction and nature of *Palaeoxyris*. (1) The supposed tubular construction is never suggested in *Vetacapsula*. (2) When it is suggested in *Palaeoxyris* and *Fayolia* the appearance is otherwise adequately explained. (3) The ' fruits ' of the Characeae are often found in association with marine organisms while *Palaeoxyris* occurs in freshwater deposits. Hence the two have rarely been recorded from the same locality and horizon.[6] (4) Transfer

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[1] Nathorst's figures are diagrammatic. Thus, his Plate vi, fig. 2a purports to represent the broken end of a cast of *P.* cf. *münsteri*, but comparison with the specimen shows the figure to be misleading, the effect of a regular hexagon being produced only by the omission from the figure of part of the matrix and by the inclusion in the figure of lines which are largely imaginary. (At the same time there is little doubt that, had the fossil been more perfectly preserved, the pedicle would have been hexagonal in transverse section). A similar diagrammatic effect has been introduced by the artist into Nathorst's Plate vi, figs 3 and 4, where the truncated ends of the specimens are shown, though a count of the segments show that perfect preservation would have resulted in a hexagonal figure.

[2] Renault, B., and R. Zeiller, *op. cit.*, 1888, especially Plate xlii, fig. 1.

[3] Crookall, R., *op. cit.*, 1930, pl. ii, fig. 1.

[4] Crookall, R., *op. cit.*, 1930, pl. iii, fig. 4.

[5] Nathorst supported his opinion as to the construction of *Spirangium* by referring to one of Ettingshausen's figures in which, among the several specimens of these forms which are apparently attached to a common axis (and therefore regarded by Ettingshausen as being all in the same stage of development), there are two sizes of organism. The larger examples are from 1½ to 2 times the breadth of the smaller and their segments are proportionally wide. He suggests that ' the larger specimens show the outer, and the smaller ones the inner mantle.' It should be observed that this difference in size does not exceed the normal amount of variation found in these fossils, and therefore calls for no special explanation. Moreover, in connection with these specimens, Nathorst, with characteristic fairness, observes ' It should, however, be mentioned that even the supposed outer mantle seems to show similar thin projecting spiral lines which may possibly have been caused by the overlying matrix through an oblique pressure.' This fact alone destroys Nathorst's case that the capsule of *Spirangium* was composed of laterally united tubes (and, consequently, that the genus was related to the Characeae). It may here be observed that there is a certain amount of variation in the width of the segments of certain species of these genera (and even in individual specimens), and this feature appears to be much more prevalent, as well as much more marked, in the post-Carboniferous than in Carboniferous examples (where the variation is remarkably small). In certain post-Carboniferous forms a variation of about 1 mm. is common. Where it exceeds 1 or 2 mm. careful examination of the specimens shows it to be due to pressure, whereby the upper and lower valves have overlapped.

[6] The only instance known to the writer is that from Ecclesbourne, near Hastings, already mentioned.

preparations made by the writer from specimens of *Palaeoxyris* show no cellular tissue. (5) The geological distribution of the two is very different. *Algites,* referred to the Charophytales, has been recorded in the Lower Devonian, associated with the Psilophytales, but *Palaeoxyris,* etc., are absent from the beds.

C. Recent View

Prof. P. Pruvost and other authors regard *Palaeoxyris, Vetacapsula* and *Fayolia* as consisting of two (sometimes more) valves, these bearing a number of ribs. *This view must be accepted and suggests a comparison with the egg-cases of fishes.*

The Arrangement of the Organisms

Specimens of *Palaeoxyris, Vetacapsula,* and *Fayolia* are usually found isolated. Those of *Spirangium jugleri* are usually in whorls. I have seen no actual union of specimens except in *Spirangium* and *Palaeoxyris.*

Kidston,[1] dealing with *Palaeoxyris,* observed ' All the specimens which have come under my notice are isolated individuals, and none has shown any attachment to a stem or branch, but twice I have seen two individuals on the same slab, so placed in relation to each other that one might suppose they diverged from a common point of attachment; that [*Spirangium*] grew in a verticillate or umbellate manner has already been shown by Ettingshausen,' and later[2] ' Ettingshausen has figured a group of seven individuals springing from a common centre, but whether this common centre is the node of a stem or the termination of a branch cannot be satisfactorily determined,' In 1890 Kidston[3] abandoned the view that *Palaeoxyris* represents plant remains.

Similarly, Lesquereux[4] stated ' I have never seen any of these spindle-shaped bodies united together, but always single,' while Moysey,[5] reviewing *Palaeoxyris* in 1910, observed, ' Ettingshausen has shown that examples of *Spirangium* occur in a verticillate or umbellate manner. Schimper[6] gives a figure of *Spirangium jugleri,* Ettingshausen, in which at least nine examples are seen arising from a common centre; and, according to his figure, it is the shorter, broader extremity that forms the point of attachment. In view, however, of the discovery of the distinct and, in some cases, perfect beak, and of the fact that the pedicle is always of variable length, and so far has not shown a definite termination, it is more probable that these organisms were attached by the pedicular end, and that the end which carried the beak was free. In those Derbyshire nodules that show two specimens, the fossils seem to lie at all angles to one another; in at least three instances they have been found to lie with their beaks approximating or even touching, but this may well be due to accidental juxtaposition.'

In 1919 Professor Pruvost[7] doubted the connection between the specimens figured by Ettingshausen,[8] and pointing out that Saporta[9] supposed an

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[1] Kidston, R., ' On the Species of the Genus *Palaeoxyris* Brongniart occurring in British Carboniferous Rocks,' *Proc. Roy. Phys. Soc. Edin.,* vol. ix, 1886, p. 57.

[2] Kidston, R., *op. cit.,* pp. 59-60.

[3] Kidston, R., ' The Yorkshire Carboniferous Flora,' *Trans. Yorks. Naturalists' Union,* part 14, 1890, p. 64.

[4] Lesquereux, L., 1880, *2nd Geol. Surv. Penn. Rep. Progress,* P., vol. ii, p. 519.

[5] Moysey, L., ' On *Palaeoxyris* and other Allied Fossils from the Derbyshire and Nottinghamshire Coalfield,' *Quart. Journ. Geol. Soc.,* vol. lxvi, 1910, p. 334.

[6] Moysey failed to observe that Schimper merely copied Ettingshausen's figure.

[7] Pruvost, P., *loc. cit.*

[8] Ettingshausen, C. von, 1852, 'Über *Palaebromelia,* ein neues fossiles Pflanzengeschlecht,' *Abhandl. d. K. K. geol. Reichsanstalt,* I Band, 3, Abth, pl. ii, fig. 3.

[9] Saporta, G. de, *Pal. franc. végét. terr. Jurass.,* iv, 1884, pp. 279-280.

example of *Palaeoxyris intermedia*, from the Coal Measures of Pennsylvania, to occur fixed on the spine of a fish, observed, ' These organisms are loose sacs which attach to anything.' Pruvost (*in litt.*) has, however, recently admitted the possibility of their having been originally united,[1] and has pointed out that the individuals of his genus *Scapellites* were probably attached to each other.

There can be no doubt that the Wealden *Spirangium jugleri* occurred in whorls, but this is the only form exhibiting such an arrangement, and it is sufficiently distinct to deserve separate generic designation. The following examples of union in this species have come under my observation :—

(1) The seven to nine specimens figured by Ettingshausen and re-figured by Schimper.[2]

(2) The three examples figured by Nathorst[3] from an unknown horizon (but probably from the Wealden).

(3) Several clusters collected by Dr. R. Florin and preserved in the Riksmuseets paleobotaniska avdelning, Stockholm. In these cases it is always the *beak* which is pointing inwards. One slab shows three, another five and still another six specimens of *S. jugleri* converging towards a common point and no doubt having been originally connected.

(4) Two clusters from Osterwald, Hanover, which are in the British Museum (Natural History). In each case the comparatively short and pointed beaks are directed to a common centre while the much longer (and twisted) pedicles point outwards. The beaks average less than 2 cm. in length, while in one instance the (incomplete) pedicle is no less than 8 cm. long.

(5) Schenk[4] figured two examples exhibiting the whorled arrangement. In one instance five, and in the other six, specimens occur to a whorl (as preserved). These were from Deister. Schenk observed, in his Explanation of Plates, that the specimens were in the München Museum, but they cannot now be traced. Professor Broili, however, has been able to provide me with a photograph of the specimen figured by Schenk on his Plate xx and this is here reproduced on Plate II at fig. 2 ; my thanks are due for his assistance.

(6) Of four slabs bearing *S. jugleri* from Deister loaned by Professor Broili from the München Museum, three show the whorled arrangement.

(7) The collections of the Geological Institute of the University of Gottingen contain, among others, a specimen which was regarded as being that figured by Schimper,[5] but though the similarity between the two is great, this specimen is quite distinct. Schimper, indeed, merely copied Ettingshausen's Plate ii, fig. 3. The Gottingen example shows six specimens in a whorl, the beaks pointing inwards. The centre of the whorl is slightly confused. Five other examples of *S. jugleri* in the Gottingen collection show the whorled arrangement. In one instance the junction at the centre is particularly clear.

(8) Of some thirty specimens of *S. jugleri* in the Geologisch-paläontologisches Institut und Museum der Universität, Berlin, kindly forwarded for examination by Professor Schuster, six show union, one case being particularly clear. The remaining specimens are fragmentary.[6]

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[1] Pruvost, P., *loc. cit.*

[2] Schimper, W. P., Traité de Paléontologie végétale, vol. ii, 1872, p. 519, Atlas, 1874, pl. lxxx, fig. 5.

[3] Nathorst's specimens apparently belonged to the Museum of the Geologische Bundesanstalt, Rasumoffskygasse, Vienna.

[4] Schenk, A., Die Fossile Flora der Nordwestdeutschen Wealdenformation, 1871, pl. xix xx, pp. 45, 66.

[5] Schimper, W. P., *op. cit.*, 1874, p. 514, pl. lxxx, fig. 5.

[6] Associated with some of these specimens are impressions of small sporangium-like bodies. They are up to 2 mm. in diameter and have smooth surfaces. Their association with *S. jugleri* is undoubtedly accidental.

(9) A slab of shale from Deister preserved in the collection of the Prussian Geological Survey, Berlin, bears impressions of two distinct whorls of *S. jugleri*. In one instance the centre of a whorl of about eight specimens is fairly clear. In the other there are about nine specimens composing an incomplete whorl the centre of which is somewhat confused.

(10) The collections of the Museum für Mineralogie, Geologie und Vorgeschichte, at Dresden, contain three examples of *S. jugleri*. One is particularly fine showing six specimens converging to a point. Another, more fragmentary, consists of three specimens which were obviously originally connected.

(11) In addition to the specimens of *S. jugleri* figured by Ettingshausen in which there can be no doubt as to the original union of the organisms, he[1] figured several examples which, owing to their incomplete state of preservation, show a portion of the beak only. It is significant, however, that in each case the beaks are pointing inwards towards a common centre and that the specimens stand at approximately the same angle to each other as in the more perfectly preserved examples. The specimen figured by A. G. Nathorst,[2] and referred to above, represents portions of three specimens of *S.* cf. *jugleri* which were, in all probability, united. Nathorst remarked that they 'appear to be united near the base,' but an examination of the specimen, as well as a comparison with more complete examples, leaves no doubt that the union, if any, was by the beak. The matrix and the specimens upon it are very similar to those known from the Wealden of Hanover and, while Nathorst described the origin of his fossil as uncertain, it probably came from the Wealden of N.W. Germany.

Turning to *Palaeoxyris*, two ironstone nodules are figured on Plate II, figs. 3 and 4, each bearing two examples of *P. helicteroides* in what may be regarded as an original arrangement[3].

Two specimens of *Palaeoxyris* figured by Dun[4] from the Hawkesbury Series (probably middle Triassic) show the same feature. In one case the beak is not preserved; in the other the incomplete beak measures about 2 cm. in length. The pedicle, on the other hand is preserved in each instance, measuring 8 or 9 cm. The organisms converge by their beaks.

With regard to *Vetacapsula* and *Fayolia*, it is scarcely to be expected that we should find the organisms in their original relationship to each other (supposing they had been connected). Both genera are extremely rare and most specimens are preserved in a fragmentary condition. Very few examples of *Vetacapsula* are known from outside Britain and of the half-dozen British specimens of *Fayolia*, none is perfectly preserved. I have seen only one instance in which two specimens of *Vetacapsula* were present on the same slab. Again, the majority of English specimens of these genera have been obtained from clay-ironstone nodules: this applies to all the specimens from the Derbyshire, Nottinghamshire and Lancashire coalfields.

The long, twisted pedicle of these organisms has hitherto been regarded as the organ of attachment or support. There can be no doubt, however, that this view is erroneous, and that on the following grounds:—

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[1] Ettingshausen, C. von, *op. cit.*, 1852, pl. i, fig. 1; pl. ii, figs. 1, 2.
[2] Nathorst, A. G., *op. cit.*, 1879, pl. vii, fig. 6, p. 13.
[3] These are probably the specimens referred to by Kidston.
[4] Dun, W. S., 'Note on the Occurrence of the Genus *Spirangium* in the Hawkesbury Series of New South Wales,' *Journ. Roy. Soc. New South Wales* for 1912, vol. xlvi, p. 205, pl. xiv.

(1) In those specimens which are connected at a common point, it is the short and tapering beak which invariably points towards the centre. The long, twisted, and unpointed pedicle, on the other hand, is directed outwards. I have seen no specimens in which the pedicles are converging towards each other as though they had been originally connected.

(2) In each genus the beak ended in a definite point, whereas the pedicle was of indefinite length.

(3) In describing *Palaeoxyris helicteroides*, the commonest species amongst these forms, Moysey[1] observed that specimens with crushed and contorted bodies occasionally possess uncrushed and complete beaks, concluding from this that the beak was more resistant to decay than the body. It is not possible to agree with this inference as (a) in all known examples of *Palaeoxyris*, *Vetacapsula* and *Fayolia* complete beaks are extremely rare, even where the body and pedicle are exceptionally well preserved. (b) The distortion of the body which occurs in so many specimens was no doubt due to the presence of an original essential organic structure, which was either shed before or decayed subsequently to fossilisation. (c) Conversely, where distortion is absent or very slightly marked (as in the smaller species of *Vetacapsula*) the beak is nevertheless usually badly preserved, though body and pedicle may be in an excellent state of preservation. (d) The uncrushed condition of the beak, when preserved, is to be expected from the fact that this organ was flattened in transverse section.

The extreme rarity with which specimens occur with their beaks intact indicates that this region consisted of less resistant tissue than the remainder of the organism. This is also suggested by the occasional presence on the fossils of small rounded protuberances (or of hollows left on their detachment) which are regarded as representing the attacks of parasitic organisms, and these objects are found especially on the beak. Moysey[2] figured one such specimen, and called attention to one of Morris'[3] syntypes of *P. helicteroides* which bears a similar marking on a segment of the body. In the collection of the Museum of Practical Geology the beaks of three specimens[4] are so affected. Hitherto similar observations have not been made with regard to *Vetacapsula* and *Fayolia*. The writer is, however, able to figure, on Plate II at fig. 1, a specimen[5] of *Vetacapsula kidstoni* bearing an excrescence on the body.

To sum up: *The somewhat distinct Wealden form known as* Spirangium jugleri *occurred in whorls. Some species of* Palaeoxyris, *including both Palaeozoic and Post-Palaeozoic forms, very occasionally exhibit a dual arrangement. Other species of* Palaeoxyris *as well as* Vetacapsula *and* Fayolia *have been found only solitary. In all cases where union of specimens is suggested, it is by the beak.*

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[1] Moysey, L., 1910, *op. cit.*, pl. xxiv, fig. 3, p. 332.
[2] Moysey, L., 1910, *op. cit.*, pl. xxiv, fig. 3 B, p. 334.
[3] Morris, J., 1840, in J. Prestwich, 'On the Geology of Coalbrookdale,' *Trans. Geol. Soc. Lond.*, 2nd ser., vol. v, Expl. to fig. 12, 12a, pl. xxxviii.
[4] Nos. Za, 2553, 2555, 2562.
[5] No. R.C.247.

Chemical Evidence

Many of the specimens of *Palaeoxyris helicteroides* preserved in ironstone nodules contain a white powdery substance which filled the cavity situated just below the centre of the body between the fossil and its counterpart (see Plate II, fig. 4). In certain instances the powder has spread to adjoining segments, occasionally covering the entire specimen as a soft crust. Specimens preserved in shale do not appear to show this feature. A similar phenomenon is also to be observed in *P. carbonaria* Schimper and in *Vetacapsula cooperi*—but only amongst examples which are preserved in clay-ironstone nodules.

Mr. R. D. Vernon[1] called attention to and examined this powder. He observed, ' This substance has been in several instances subjected to microscopical examination, with and without chemical solvents, but, so far, nothing has been found that throws any light on its original nature. Chemically, this substance has been found to consist of ferrous carbonate. A careful search for phosphates, the presence of which it was thought, might point to the animal nature of the fossil, has yielded only a negative result. If these fossils are really egg-capsules, it is very unlikely that any relics of the embryo would be found, as in all probability they would be the spent egg-cases, drifted to their present position by currents; just as rarely, if ever, do we find the embryo skate still contained in the ' sailor's purse ' of our coasts.'

Mr. E. G. Radley has kindly repeated these chemical tests with 10 specimens[2] and reports that all contain silica or white clayey material as well as ferrous carbonate. Contrary to the result obtained by Mr. Vernon, Mr. Radley detected very slight traces of phosphates in three instances.[3]

The presence of small quantities of phosphates in these remains cannot, however, be regarded as furnishing any criterion as between their origin from plants or animals. Were they egg-cases of fishes, the embryos would almost invariably be absent; were they plant remains, the phosphate-content would depend on the composition of the soil and on the part of the plant preserved.

Variation in Size

Professor W. W. Watts[4] has pointed out that the variation in size in the organisms is ' not in favour of the origin of *Palaeoxyris* as an egg-capsule.' The writer[5] has shown that this variation within a given species is even greater than was then supposed.

When dealing with the dimensions of *Palaeoxyris helicteroides*, Moysey[6] rightly excluded the pedicle, as this is variable. The critical dimensions are

[1] In L. Moysey, 1910, *op. cit.*, p. 332.
[2] Collection of the Museum of Practical Geology, Nos. Za, 2496, 2697, 2560, 2705, 2515, 2587, 2545, 2546, 2522, 2505.
[3] Nos. Za, 2560, 2587, 2705.
[4] Watts, W. W., in L. Moysey, *op. cit.*, 1910, p. 345.
[5] Crookall, R., *op. cit.*, 1930, pp. 16, 18, 26.
[6] Moysey, L., *op. cit.*, 1910, p. 331.

the length of body and beak, and the width of the body at its broadest point. His specimens of *P. helicteroides* varied from 3.5 cm. to 10.8 cm. in length and from 1 to 3 cm. in breadth. The 42 specimens of this species preserved in the Manchester and Oldham Museums were found by Dr. W. J. Jackson[1] to be from 5 to 6.6 cm. long by 1.0 to 1.2 cm. wide.[2] The writer[3] has recorded an example of *P. helicteroides* which was no less than 3.8 cm. across, while one in the British Museum[4] is only 7 mm. wide. The syntypes[5] of this species are preserved in the British Museum (Natural History)[6] and measure only 1 cm. across. In No. V.3628 the beak is apparently complete, but in No. V.3124 it is incomplete. In each case it is 1.5 cm. long. The (incomplete) pedicle measures 1.9 cm. in length in the former and 1 cm. in the latter.

It is not sufficient, however, merely to describe the extreme limits of a species. A better conception of the variation in size is obtained from a number of individual measurements and, as the beak is usually either absent or incomplete, it is preferable to give the dimensions of the body as distinct from either beak or pedicle. The following figures are obtained from 30 examples of *P. helicteroides*:

Width (cm.)	Length of body (excluding beak and pedicle —cm.)	Beak* (cm.)
1	3.2	1.6
1	3.2	1.5
1.7	3.5	—
1.9	4.5	—
1.6	4.3	—
1.4	3.7	—
1.4	4.0	—
1.6	3.7	—
1.4	3.4	2.3
1.5	2.8	1.0
1.4	3.7	2.3
1.7	3.5	2.7
1.1	3.0	—
1.2	3.7	—
1.1	2.8	—
1.0	3.0	—
3.0	6.0	—
2.2	5.5	—
1.0	3.0	—
2.5	6.0	—
1.1	2.8	—
1.2	3.4	2.1
1.3	3.0	1.3
1.4	4.5	2.0
0.7	3.0	—
1.0	2.7	—
1.7	4.3	—
3.8	?	—
2.7	6.0	—
1.5	3.0	—

* Where a figure is not given, the beak was absent: in most other instances it was incomplete.

[1] Jackson, J. W., *Lancashire Naturalist*, 1911, p. 328.
[2] The longest pedicle was 4.1 cm. and the shortest 2.3 cm.
[3] Crookall, *op. cit.*, 1930, p. 16.
[4] No. V. 12927.
[5] Morris, J., 1840, in J. Prestwich, 'On the Geology of Coalbrookdale,' *Trans. Geol. Soc. Lond.*, 2nd Ser., vol. v, Expl. to figs. 12, 12a, pl. xxxviii. (The spiral twist on the pedicle is not well shown in the drawings, though they are very good in other respects.)
[6] No. V.3628 (and its counterpart, No. V.4259): V.3124.

The limits of size which apply to other species of the genera can be seen in the following table:—

	Width (cm.)	Length (cm.)*
Palaeoxyris trispiralis Kidston	2.0—3.5	4.0— 9.0
Palaeoxyris prendeli Lesquereux ...	1.0—1.2	2.5— 3.0
Palaeoxyris bohemica Crookall	1.5—5.0	5.0—14.0†
Palaeoxyris carbonaria Schimper ...	0.7—1.2	2.5— 4.0
Vetacapsula johnsoni (Kidston) ...	1.4—2.1	2.2— 4.5
Vetacapsula cooperi Mackie	2.5—4.6	2.5— 4.9
Vetacapsula moyseyi Crookall	2.7—5.6	2.2— 4.7
Vetacapsula kidstoni Crookall	0.3—0.6	0.6— 1.4
Fayolia randalli (Newberry)	1.3—2.5	7.0—17.0†
Fayolia dentata Ren & Zeill.	1.5—2.5	8.0—16.0

* The length of body here given excludes the pedicle and the beak.
† Or more.

While the variation in size of these organisms is seen to be considerable, this can scarcely be taken as having any direct bearing on their nature and affinities.

Associated Remains

Examples of *Palaeoxyris*, etc., always occur in fresh- or brackish-water deposits and usually in association with plant remains and fresh- or brackish-water molluscs.[1] I do not know of any authentic instance of their occurrence in a marine band[2] though, very occasionally, they have been found with fish remains.[3] Nodules containing specimens of *Palaeoxyris*, etc., in the collections of the Museum of Practical Geology, the British Museum (Natural History) and of Mr. H. W. Hughes of Dudley also contain plants.

Many authors[4] who have recorded these remains have noted their association with plants, while they are often found with freshwater shells. Thus,

[1] Mr. W. Hemingway has pointed out (*in litt.*) that he has found *Palaeoxyris* in association with *Prestwichianella* (=*Prestwichia*), and this was also the case in the Coalbrookdale area. W. H. Bailey (in H. Woodward, 'Monograph of the British Fossil Crustacea,' *Palaeont. Soc.*, 1878, p. 243) observed that, with an allied form (*Belinurus*), *Prestwichianella* probably occurred in freshwater and estuarine deposits and that this view accords with those of Martin and Prestwich. Mr. Hemingway suggests that the association noted above 'May have some bearing on the nature of *Palaeoxyris*,' but this is not possible. The geographical and geological range of the two is also very different.

[2] Dr. H. Bolton 'Faunal Horizons in the Bristol Coalfield,' *Quart. Journ. Geol. Soc.*, vol. lxvii, 1911, p. 316, pl. xxvii, figs. 20, 21, recorded *Palaeoxyris helicteroides* from a bed 279 feet below the Bedminster Great Vein in the Bristol Coalfield. This bed he described as yielding both freshwater and marine forms, but did not state with which shells the specimen of *Palaeoxyris* was associated. Again, in noting the occurrence of *Vetacapsula cooperi* in the 'New Mine' or 'White Ironstone' of Dudley, Mr. J. P. Capewell (in Mackie, J., '*Vetacapsula cooperi*,' *Geol. and Nat. Hist. Repertory*, vol. i, 1865-7, pp. 216, 217) observed that while he had not found the organism in any other measure, 'In the same measure are also found *Calamites*, *Stigmaria* and *Neuropteris*: and it has for its fauna *Myalina*, *Anthracopecten*, *Productus* and a *Limulus*.' This statement is unreliable and very probably inaccurate.

[3] Dun, W. S., 'Note on the Occurrence of the genus *Spirangium* in the Hawkesbury Series of New South Wales,' *Journ. Soc. New South Wales for* 1912, vol. xlvi, p. 205.

[4] Jackson, J. W., *op. cit.*, 1911, p. 326. R. Crookall, 1928, pp. 95, 102.

with regard to the specimens from boreholes in the Cwmgorse valley, South Wales, collected by Miss E. Dix and Professor A. E. Trueman, and recorded by the writer (*op. cit.*, 1928, pp. 99, 101), Miss Dix observed that they were accompanied by plants, Carbonicolas and Naiadites and concluded (*in litt.*) ' There are neither fish-beds nor marine bands anywhere near the horizons with *Palaeoxyris* from the boreholes.'

The Fairlight Clays of Ecclesbourne, which have yielded the only known British Mesozoic examples of *Spirangium*, are freshwater deposits, while Dr. R. Florin gives the following list of remains associated with *Spiranguim jugleri* from the Wealden of Egestorf, Deister, Hanover :—*Onychiopsis mantelli* (Brongt.)—common ; *Laccopteris dunkeri* Schenk—rare, and in small fragments only ; *Nilssonia schaumburgensis* (Dunker)—rare ; *Sphenolepidium kurrianum* (Dunker)—rather common ; *S. sternbergianum* (Dunker)—rare ; *Sciadopitys sp.*—undescribed fragments of double needles—rare. He concludes with the following observation : ' Thus, *Spirangium* is here associated with the typical Wealden flora.[1] In addition we found a freshwater mollusk, probably belonging to *Unio planus* A. Röm., to be rather common. The fragments of *Spirangium* are, however, the most common of all organic remains in this type of rock at Egestorf (Deister).'

Herr F. Nindel of Chemnitz informs me that he has found no marine beds in the Borna-Chemnitz locality from which he obtained his specimens of *Fayolia*.

The fact that these remains occur in fresh- or brackish-water deposits and often associated with plant remains has been regarded as indicating their origin from plants rather than from fishes. This is not the case as will be seen from the observations made on p. 138. *It may also be pointed out that the terms ' fresh,' ' brackish ' and ' salt ' are vague, and other important factors must be taken into consideration.*[2]

Surface Markings

In comparing these remains with the egg-cases of sharks, etc., reference has frequently been made by various authors to striae, running parallel to the ribbing, which sometimes occur on the bands.

A. Direction of the striae

The following Table shows Palaeozoic species in which striae have been observed :—

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[1] It should be noted that *S. jugleri* is regarded as distinct from most forms here treated.

[2] The salinity of the sea has considerably increased since Palaeozoic times. This factor, at present about 35 per 1000, has been estimated by G. Simoens (*in* ' Memoir on the Coalfields of Ireland,' *Dublin*, 1921, p. 358) as being about 10 per 1000 in Coal Measure times. Moreover, it is to be expected that differences between marine and non-marine animals have been accentuated in the course of evolution. Finally, the presence in waters of salts other than sodium chloride must be taken into consideration.

	Vetacapsula	*Palaeoxyris*	*Fayolia*
Striae parallel to the ribbing	*V. cooperi* Mackie (on 2 specimens)	*P. prendeli* Lesqx. (on 1 specimen) *P. helicteroides* (Morris) (on 20 or more specimens)	*F. sterzeliana* Weiss (on 2 specimens) *F. crenulata* Moysey (on 2 specimens) *F. warei* Crookall (on 1 specimen) *F. grandis* R. & Z. (on some specimens) *F. moyseyi* Pruvost (on 1 of the 2 known specimens) *F. interstrialis* (Stanier) (on 1 specimen)
Transverse striae	—	*P. helicteroides* (Morris) (on 12 or more specimens) *P. prendeli* Lesqx. (on 2 specimens)	—
Oblique striae	—	*P. prendeli* Lesqx. (on 2 specimens)	—

Striae have not been observed in: *Vetacapsula moyseyi, V. johnsoni, V. kidstoni, V. minima, Palaeoxyris carbonaria, P. trispiralis, P. warei, P. pringlei, P. edwardsi, Fayolia dentata, F. palatina* and *F. randalli.*

Hitherto striae have not been observed on Mesozoic specimens of *Palaeoxyris* and *Spirangium.* They occur on some few examples, however (e.g., on a portion of a specimen of *Spirangium jugleri* from the Fairlight Clays of Hastings, in the Brighton Museum, No. G.6542). In this instance the markings are coarse and parallel to the ribbing: they are confined to a single segment and appear to have been caused by pressure.

B. Distribution

Very rarely are striae equally distributed over the entire surface of the fossil, although the specimen may appear to be equally

well preserved throughout. On the contrary, their occurrence is almost always local—as a rule they are confined to only a few segments, the rest of the organism being either smooth or bearing marks running in a different direction. Thus, the beak may bear striations parallel to its margin while the body has (locally) transverse markings, or *vice versa*.[1] Again, transverse lines may be superimposed on parallel, each type nevertheless predominating on different parts of the fossil.

It is probable that, while the markings which are found running parallel to the ribbing in certain species may represent original features in the organisms, those which follow other directions are the result of accidents in fossilisation. The frequency of parallel markings supports the egg-capsule theory.

Surface Covering

Plant remains are usually encrusted with a carbonaceous film. Moysey[2] observed that his specimens of *Vetacapsula, Palaeoxyris* and *Fayolia* did not show any trace of such covering, while Pruvost has remarked on its absence from the fourth genus *Scapellites*. The traces of cells referred to by Renault and Zeiller[3] in their original account were due to accidents of fossilisation.

It should be noted, however, that the vast majority of Moysey's specimens were preserved in ironstone nodules and that Palaeozoic examples of these genera preserved in shale are extremely rare. Professor Seward[4] called attention to the absence of a coaly layer from his specimen of *Fayolia* from the Stainton Quarries of Barnard Castle, while Professor Pruvost[5] observed that in the specimens he had examined the surface suggested a chitinous covering.

As is well known, the stems and leaves of the living Equisetales are strongly impregnated with silica. It seemed not impossible that a similar impregnation occurred in Palaeozoic times and may have affected the formation of a carbonaceous layer in fossilisation. Some authors, indeed, as for example E. S. Moore,[6] assume that the Palaeozoic Equisetales were so incrusted, observing that silica in the ash of coals is ' derived partly from such plants as the ' horsetails ' which may contain upwards of 12 per cent. of it in their stems.' Professor Seward, however (*in litt.*), informs me that the earliest case in which a' horsetail ' is known to be impregnated with silica is that found by Dr. T. Harris in

[1] Transverse marks occur on the body and parallel marks on the beak of specimen No. Za. 2557, Museum of Practical Geology.
[2] Moysey, L., *op. cit.*, 1910, p. 334.
[3] Renault, B., and R. Zeiller, *loc. cit.*
[4] Seward, A. C., ' A New Carboniferous Fossil,' *The Naturalist*, 1894, p. 234.
[5] Pruvost, P., *loc. cit.*
[6] Moore, E. S., ' Coal,' *New York*, 1922, p. 37.

the Rhaetic of Greenland. Again, the surfaces of stems (and especially of rhizomes) of *Calamites undulatus* (Sternb.), an Upper Carboniferous plant, are covered by a carbonaceous layer which, when magnified, is seen to consist of large rectangular cells. Finally, Dr. S. Leclercq observes (*in litt.*) 'I have never noted a particular impregnation with silica in the Carboniferous Equisetales.' The Mesozoic examples of the genera under discussion exhibit no carbonaceous covering.

The writer has applied the method of transfer which was worked out by Mr. Ashby in Professor W. H. Lang's laboratory,[1] to specimens of *Spirangium, Vetacapsula, Palaeoxyris* and *Fayolia*, and although in many cases the results were negative, obtained preparations from all four genera as follows:—

Spirangium jugleri from the Wealden of Deister.
Palaeoxyris helicteroides from the Coal Measures of Britain.
Vetacapsula kidstoni from the Coal Measures of Wales.
Fayolia sterzeliana from the Coal Measures of Silesia.

In no case was any cellular tissue observed. This must be regarded as conclusive evidence that the organisms represent animal and not plant remains.

Affinities

In 1919 Professor Pruvost[2] accepted the theory that *Vetacapsula, Palaeoxyris* and *Fayolia* represent the egg-cases of fishes. He considered that the animal nature of the remains was beyond doubt, referring to the lack of carbonaceous matter and to the chitinous covering of the specimens. He[3] summarized the position of Zeiller (1890) that these fossils represent animal remains and are to be regarded as the egg-cases of Elasmobranchs as follows: the eggs of most true oviparous plagiostomes are enclosed in a case which takes the form of a rectangular sac composed of two united valves, ornamented by a variable number of longitudinal ridges, and prolonged into two processes above and below, one serving as an organ of attachment.

Pruvost's comparison of the fossil with recent forms may be tabulated as follows:

[1] The Ashby Transfer Method was described by Professor W. H. Lang in *Annals of Botany*, vol. xl, 1926, p. 710.
[2] Pruvost, P., 'La faune continentale du terrain houiller du nord de la France,' *Mém. Carte Géol. dét. de la France*, 1919, p. 439.
[3] Pruvost, P., *op. cit.*, p. 440.

	Shape of sac	Twisting of valves	Ornamentation	Frequency
RECENT FORMS *Cestracion phillipi*	conical	spirally twisted	ridges form two collarettes	rare
Chimaeroids	flatly fusiform	not twisted	two collarettes formed by union of fibrous hairs	common
FOSSIL FORMS *Fayolia*	fusiform	spirally twisted	collarette in Fayolia; spines compared with hairs forming collarette in Chimaeroids	rare
Palaeoxyris	do.	do.	simple ridges as in Rays	fairly common
Vetacapsula	do.	not twisted	do.	rare

It will be seen that all the characters occurring in the fossil forms occur in the egg-sacs of living fish, though they are differently grouped. Pruvost pointed out that a possible origin from the Chimaeroids can be ruled out as the group did not appear until Mesozoic times. Of the Elasmobranchs, the Acanthodides did not, so far as is known, produce egg-cases. Moreover, in the Old Red Sandstone of England and Nova Scotia, where the Acanthodides are frequent, *Palaeoxyris,* etc., are absent. Finally, Professor D. M. S. Watson points out (*in litt.*) that no Acanthodian is known to have survived more recently than the Lower Permian. The group can, therefore, be dismissed as representing a possible origin of our fossils.

Moysey[1] was tempted to regard *Palaeoxyris* and *Fayolia* as belonging to the Ichthyotomes, the simplest of the Elasmobranchs. He described them as the 'generalised ancestors of both the Cestracionts and the Chimeroids.' The Ichthyotomi, however, extend to the Upper Trias and are not known subsequently.

Zeiller (1890) figured the Coal Measure fish *Pleuracanthus gaudryi,* an Ichthyotome, as the probable origin of *Fayolia dentata,* but regarded *Palaeoxyris* as belonging to the Selachians. Pruvost agreed and would also refer *Vetacapsula* to the Selachians. He

[1] Moysey, L., *loc. cit.*

pointed out that this difference in origin of *Fayolia* and *Palaeoxyris* is supported by their stratigraphical distribution.

Dealing with the possible objection that *Vetacapsula, Palaeoxyris* and *Fayolia* always occur in freshwater deposits and generally in association with plant remains, Professor Pruvost pointed out that the Ichthyotomes are scarcely true marine forms and that, though the Selachians are marine, (*a*) the distinction between salt- and freshwater deposits is not always sharp[1]; (*b*) the teeth of Selachians are associated with freshwater molluscs in England; (*c*) as is the case with certain of the present-day dog-fish, the Coal Measure Selachians probably entered the mouths of rivers and possibly penetrated into lakes to lay their eggs.[2]

Professor D. M. S. Watson (in litt.) *observes that, 'if animal, the organisms can, I think, only be egg-cases of an Elasmobranch, and the obvious immediate comparison amongst recent forms is with* Cestracion, *whose capsule may be regarded as built up from two lamellae stuck together so as to leave two projecting frills and then twisted into a spiral with an aperture at each end. My original difficulty was that* Palaeoxyris *ranged from the Lower Carboniferous to the Wealden and that no form of fish did. Now, however, Mr. Brough, working here, has found that unquestionable members of the family Hybodontidae are present in the Lower Carboniferous of Scotland, so that the range of the family extends certainly from the Lower Carboniferous to the Wealden, and many of its members,* Acrodus capensis, *for example, in the Lower Trias, and* Hybodus strictus *from the Wealden, are found in rocks of fresh water origin. Dr. Smith Woodward holds that the family also occurs in the Chalk, and it is not impossible that it extended backwards into the Upper Devonian, and would then cover the known time range of* Palaeoxyris *very accurately.'*

As to the possible attribution of Fayolia *and* Vetacapsula, *Professor Watson observes that, while marine forms can be excluded, whether they belong to other groups of the Elasmobranchs is disputable. The possible forms are the Ichthyotomi (ranging from the Lower Carboniferous to the Upper Trias), the Petalodontidae (Lower Carboniferous to Upper Permian), Cochliodontidae (Lower Carboniferous to Upper Permian) and Cladodontidae (Upper Devonian to the Lower Permian), their vertical range thus giving no assistance,* Fayolia *being found in the Upper Devonian, Lower Carboniferous, Upper Carboniferous and Lower Permian, but* Vetacapsula *being restricted to Upper Carboniferous.*

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[1] See also footnote 2 on p. 133.

[2] One difficulty remains to be explained with regard to the whorled arrangement in the Wealden *Spirangium jugleri*, which has been illustrated at Plate II, fig. 2. Professor D. M. S. Watson (*in litt.*) observes, 'The mode of formation of Elasmobranch egg-capsules, so far as is known, allows only of the production of two at a time, one in each oviduct, and I have great difficulty in imagining any modification which would allow of others being formed whilst the original pair were in storage; thus, it is difficult to imagine an Elasmobranch laying more than two at one time, not simultaneously, but one shortly after the other. In the case of the dogfish, the female protrudes the long strings in which the capsule ends through the cloaca, entangles them in seaweed, and then swims round and round in circles so as to ensure the attachment. She then goes away and lays another, so that it would only be by accident that two or more became attached to the same weed.'

Summary

1. Nathorst's suggestions (*a*) that *Palaeoxyris* consisted of laterally united spirally arranged tubes and (*b*) that it might represent the oogonium of gigantic freshwater plants of Characean relationship are examined and rejected.

2. Specimens of the Wealden *Spirangium jugleri* were attached in a whorl at a common centre. *Palaeoxyris helicteroides* and some other species occasionally had a dual arrangement. On the other hand, other species of *Palaeoxyris* and all known examples of *Vetacapsula* and *Fayolia* have been found only singly.

3. Attachment was by the pointed beak; not by the twisted pedicle.

4. The beak was composed of less resistant material than the pedicle.

5. Traces of phosphates have now been detected in the fossils.

6. The degree of variation in size of the organisms is great.

7. The remains invariably occur in fresh- or brackish-water deposits, often in association with plants or fresh- or brackish-water molluscs.

8. Striae running parallel to the ribbing may represent original features in the organisms, but those taking other directions have resulted from accidents in fossilisation.

9. Carbonaceous matter is absent from the surface. Transfers have been prepared from examples of all four genera. *The entire absence of cellular tissue from these preparations precludes their being plant remains.*

10. As they are of animal origin, the obvious comparison is with the *egg-cases of Elasmobranchs.*

11. Professor D. M. S. Watson observes that Mr. Brough has found that *the family Hybodontidae* occurs from the Lower Carboniferous to the Wealden in a typical form. It is possible that it goes back into the Upper Devonian and on into the Chalk, and therefore *covers the necessary geological period of Palaeoxyris very accurately.* With regard to *Vetacapsula* and *Fayolia,* he cites as possible forms the Ichthyotomi, Petalodontidae, Cochliodontidae and Cladontidae, their geological range, however, providing no assistance.

Explanation of Plate II

Fig. 1. *Vetacapsula kidstoni* Crookall. × 3.
Horizon: Brass Vein (Yorkian Series).
Locality: Diamond Slant, Ystradgynlais, Swansea.
Collected by Mr. W. D. Ware.
Collection: Museum of Practical Geology, No. R.C.247. The specimen shows a globular body attached at about two-thirds up the organism. This probably represents a parasitic organism.

Fig. 2. *Spirangium jugleri* Ett. × 2/3.
Horizon: Wealden.
Locality: Deister, Hanover, Germany.
Photograph by Professor F. Broili of the specimen drawn by Schenk in 1871 (his Plate xx), showing five specimens attached to a common centre.

Fig. 3. *Palaeoxyris helicteroides* (Morris). × 1.
Horizon: Waterloo Coal (Yorkian Series).
Locality: Meadow Lane Clay-pit, Alfreton, Derbyshire.
Collected by Dr. L. Moysey.
Collection: Museum of Practical Geology, No. 48773. The photograph shows two specimens converging and touching by their beaks.

Fig. 4. *Palaeoxyris helicteroides* (Morris). × 1.
Horizon: Top Hard Coal (Yorkian Series).
Locality: Digby Clay-pit, Kimberley, Nottinghamshire.
Collected by Dr. L. Moysey.
Collection: Museum of Practical Geology, No. 48772. Two specimens are converging by their beaks.

VETACAPSULA, SPIRANGIUM AND *PALAEOXYRIS.*

X.—THE STANKARDS SILL

BY

SIR JOHN S. FLETT, K.B.E., F.R.S.

Plate III; Text-figure 1.

IN 1918 a boring was put down at Stankards, West Lothian, by the Broxburn Oil Company, in search of oil-shale, and at a depth of 102 ft. it entered a sill which persisted to a depth of 319 ft. 6 in. and was consequently 217ft. 6 in. thick. Forty specimens were collected from the core by Mr. David Tait of the Geological Survey of Scotland, being one for every six feet in depth and a few extra specimens near the top and the bottom of the sill. Microscopic sections have been prepared from these specimens (S.27966-28004) and are the subject of this report. The sill consists of essexite, teschenite, olivine diabase, picroteschenite and picrite and shows a number of interesting features.

The Stankards boring (No. 2 Stankards in the records of the Geological Survey of Scotland) is situated a few hundred yards east of the outcrop of a basic sill which is probably part of the Houston Wood sill, detached by an east-and-west fault. Stankards is a farm about half a mile south of the village of Uphall. The Houston Wood sill as represented on the one-inch geological Sheet 32 (Scotland) has a large irregular outcrop with an area of more than a square mile. From the ' Drift ' edition of Sheet 32, however, it will be seen that nearly the whole of this outcrop is covered by boulder-clay and there are only a few quarries or openings from which the solid igneous rock can be obtained. In the third edition of Sheet 32 (published 1910) the outcrop was labelled tD signifying teschenite. In the fourth edition, however (1930), the index letters have been changed to ' tD near qtD ' to imply that as a teschenite it is somewhat abnormal and approaches the quartz-dolerites in certain characters. Included in the outcrop as shown on the one-inch Sheets, near Howden in the south-west corner of the outcrop, there is a mass of undoubted quartz-dolerite; it is probable, however, that this is a separate and distinct intrusion, the relations of which to the main sill are obscured by the cover of drift. The horizon of the Stankards and Houston Wood sills lies between the Dunnet and the Broxburn oil-shales; it seems in every way probable that they are the same intrusive mass.

There are certain characters of the sill that are unusual in the teschenite sills of the Lothians. The most striking of these is the scarcity, and in fact the complete absence, of analcite from many of the specimens collected either from outcrops or from borings. As analcite is the typical mineral of the teschenites its absence or rarity gives a marked peculiarity to this sill. There can be no

doubt, however, that the Stankards sill is a member of the teschenite series and in the Lothians at any rate this series is very distinct from the quartz-dolerites. Primary quartz or micropegmatite have not been found in any of the microscopic sections prepared from the rocks of the Stankards boring.

Another striking feature of this sill is the great mass of picrite which it contains. From 66 ft. to 189 ft. from the upper surface of the sill the rock is a typical picrite, sometimes much decomposed but often in a remarkably fresh condition. No other sill in the Carboniferous rocks of Scotland contains an ultrabasic mass of that size. From the surface outcrops the presence of this picrite (123 ft. thick) had never been suspected.

Petrographical Characters

The immediate contact of the sill with the overlying rock is not represented in the specimens collected. It is clear, however, that both at top and at bottom of this sill the usual band of ' white trap ' did not exist; and this seems to show that a white trap margin is found only where basic sills occupy the position of highly carbonaceous rocks such as oil-shales and coals.

A specimen taken 18 in. from the top of the sill resembles an olivine diabase with rather abundant secondary minerals such as serpentine, chlorite, calcite. It has originally contained little olivine and that mineral is now entirely decomposed. Augite is rather more frequent and often still in good preservation though in part replaced by chlorite and secondary albite. Dark brown biotite is rather conspicuous in the rock section and often surprisingly fresh. In addition to iron ores the other primary mineral is felspar which makes at least five-sixths of the whole rock. The felspar is principally albite with good polysynthetic twinning. Its lath-shaped sections are often 1 mm. in length so that the rock cannot be described as a fine-grained chilled edge. Most of the albite is undoubtedly primary though some measure of albitization cannot be excluded. A rock with such a composition is abnormal as a diabase. It belongs evidently to the group described in the Edinburgh Memoir[1] as *essexites,* which are characterized by a high percentage of alkali felspar. A description and analysis of the Lochend essexite are given in that memoir. The striking feature of this rock, however, is the absence of analcite and zeolites.

The next specimens, taken three feet from the upper surface of the sill, are typical *teschenites* rich in analcite both primary and secondary. The analcite not only occupies irregular interstitial areas between the other rock components but it has also spread through the felspars till in many cases they are reduced to pseudomorphs having the original lath-shapes of the primary mineral replaced by analcite, chlorite and carbonates. The

[1] 'The Geology of the Neighbourhood of Edinburgh' (*Mem. Geol. Surv.*), 1910, p. 292.

honeycombed residues of the original felspar are mostly albite with some orthoclase or perthite. The olivine, originally not abundant, is now represented wholly by serpentine. Augite is partly fresh, of pale reddish-brown colour, but is often decomposed to chlorite. Biotite is strikingly abundant in flakes dark chestnut brown and intensely pleochroic; it is the best preserved of the original minerals. Iron ores, titaniferous, in skeletal networks passing into leucoxene, are conspicuous in the sections. Unfortunately the specimens taken at this horizon were not large enough to provide material for a complete chemical analysis.

A specimen taken six feet from the top of the sill is an *olivine diabase* exceptionally rich in ferromagnesian minerals (olivine and augite). For the next sixty feet in depth the rock does not change very much in character or composition. The specimens collected at distances of one fathom apart, though very similar, are not free from minor differences, especially in the relative proportions of felspars and ferromagnesian minerals, but it is evident that in the lowest twenty feet of this band there is a general though gradual increase in the dark-coloured constituents. Felspar, however, continues to be a prominent ingredient of the rock sections. Analcite has not been detected in these rocks. This zone is on the whole fairly coarsely crystalline as the felspars attain a length of 3 or 4 mm. The specimens are all more or less ophitic, as the pyroxenes are of irregular shape and are usually moulded on the elongated prismatic felspars, but, as the augite is not very plentiful, the ophitic structure is not well marked. In colour the augite is pale reddish-brown, sometimes greenish-brown, with fairly distinct dispersion of the axes, but it has seldom the plum colour so often seen in the augite of the teschenites. Dark brown biotite is quite frequent, usually enveloping latticed growths of titaniferous iron oxide. Chlorite and serpentine make up a large part of the rocks; no fresh olivine has been observed in this zone.

In the microscopic sections of the rocks of this zone a very striking feature is the prevalence of albitization. Some of the rocks have their felspars so completely albitized that they may be described as albite-diabases. In most cases, however, a certain amount of the original lime-bearing plagioclase remains as cores in albite or as islands surrounded by albite. The albitization is irregularly distributed, for in the same slide a cluster of plagioclase crystals may be completely albitized while an adjacent part of the slide may show residues of plagioclase still undemolished. Every stage in the process may be observed, as the new albite grows around the plagioclase, slowly spreading inwards and sending veins across the lath-shaped sections which gradually enlarge till the whole mass is solid albite. The analogy with analcitization is very close and obvious, and it is evident that the processes are of the same kind. In these albite pseudomorphs after plagioclase there are often patches of chlorite, which may occupy a central position, or may form zones parallel to the

crystal boundaries and separated by zones of albite. As much as one third of the space occupied by the crystal may be filled in this way by the infiltration of chlorite.

There are certain microscopic characters by which this secondary albite can be easily recognized. It is never clear, glassy and homogeneous. In ordinary light it has the granular appearance of a ground glass surface. This is owing to the presence of innumerable minute specks of a mineral with higher refractive index embedded in a matrix of albite. In polarized light the secondary albite is ' speckled '; in the dull grey matrix of albite, which has the usual low polarization colours, there are bright scintillating specks of another mineral (Plate III, figs. 5 and 6), which has bright colours, usually yellow to pale red of the first order. These specks are usually not more than a hundredth of a millimetre in greatest diameter, and often much smaller than this. They are scattered quite irregularly through the albite and have no definite orientation, so that as the microscope stage is rotated they twinkle in the polarized light, giving an appearance to the sections that is perfectly characteristic.

One notable feature of their distribution is that they are often most numerous towards the centre of a pseudomorph, gradually diminishing in abundance in the outer zones. It is reasonable to infer that the original crystal was zoned, and had a larger percentage of anorthite in its central than in its peripheral parts; and the minute speck-like inclusions are a secondary mineral developed at the expense of primary anorthite. In fact where residual plagioclase can be observed that is still fresh it proves to have a highly zonal structure with cores of bytownite or labradorite passing outwards into oligoclase or albite. It is also evident that original zoned plagioclase is never ' speckled.'

Most of these granules, flakes and fibres in the speckled felspar are much too small to be accurately diagnosed by means of the microscope. Their characters, however, accord very well with the hypothesis that they are prehnite. It has been suggested that the granules in speckled albite may be epidote or zoisite, but in the rocks under description this cannot be reconciled with their behaviour in polarized light. On the other hand no large crystals or plates of prehnite have been observed.

Considered from the standpoint of chemical composition the probability that the specks in speckled albite are prehnite presents no difficulties. Owing to the prevalence of analcitization in the rocks of the teschenite series we are at liberty to assume that shortly after the consolidation of these rocks there was an influx of soda-bearing solutions by which the analcite was deposited. These solutions were probably accompanied by gases such as CO_2 and probably also the aqueous medium contained silica in solution, free or combined with soda.

The following equations may represent the chemical changes that take place in the albitization of plagioclase with the formation of prehnite and albite.

$$2\,CaAl_2Si_2O_8\ (\text{Anorthite}) + Na_2O + 5\,SiO_2 + H_2O = H_2Ca_2Al_2Si_3O_{12}\ (\text{Prehnite}) + 2\,NaAlSi_3O_8\ (\text{Albite})$$

This formula would indicate that each molecule of soda added to the rock produces two molecules of albite; furthermore the additional matter introduced is largely silica, for 5 molecules of SiO_2 accompany one of Na_2O. In this transformation about equal quantities of prehnite and albite result from the albitization of the anorthite. If we suppose the average plagioclase of the original rock to have been a labradorite with 50 per cent of anorthite and 50 per cent of albite the albitized rock will contain about 75 per cent of albite and 25 per cent of prehnite.

Similarly we may consider that the formation of analcite after plagioclase may take place in the following manner if the analcite is accompanied by calcite as is often the case.

$$CaAl_2Si_2O_8\ (\text{Anorthite}) + Na_2O + 2\,SiO_2 + 2\,H_2O + CO_2 = Na_2Al_2Si_4O_{12}.2H_2O\ (\text{Analcite}) + CaCO_3\ (\text{Calcite}).$$

These equations seem to indicate that the formation of analcite required the presence of more soda and less silica than the production of albite after anorthite.

The process, however, is not quite so simple as these equations might lead us to imagine. It is clear, for example, that much chlorite is produced in the albitized rocks and this chlorite is very closely associated with the speckled albite, in fact it forms clumps, streaks and zoned infillings in many of the crystals. The chlorite cannot be assumed to have arisen from the alteration of the augite, which is usually in very good preservation. The olivine, however, has been changed to serpentine and by the addition of alumina to serpentine, minerals of the chlorite group may be formed. Another process that has certainly gone on to a considerable extent is the formation of sphene (leucoxene) after ilmenite, and in this way part of the lime set free by albitization of anorthite may have been used up.

At depths of 50 to 60 ft. in the sill the rock is much decomposed and so liable to crumble that it is difficult to prepare microscopic sections. At 66 ft. however it has definitely changed to *picrite* in which olivine is the dominant mineral. At 70 ft. the picrite is fresh enough to show a considerable proportion of olivine unaltered to serpentine, which has not been observed at any of the higher horizons. From 66 ft. to 189 ft. the bore continued in picrite of very uniform character. Down to 159 ft. the rock contained fresh olivine. The next 30 ft. are badly decomposed and at 189 ft. the rock passes into a picroteschenite which persists to the bottom of the sill at 217 ft.

As the picrite shows little variation from top to bottom it will be sufficient to consider the microscopic character of the analysed specimen (27983, from a point 90 ft. below top of sill). This consists of olivine, augite and felspar with biotite and iron ores. The olivine forms about one half of the rock. Its crystals are small, seldom more than 1 mm. in greatest dimension. They may show quite good crystalline outlines but are commonly rounded at their corners. More than half of the olivine is fresh, the remainder being converted into yellow and green serpentine. The augite is pale reddish-brown in colour and forms large plates up to 4 or 5 mm. in diameter. They always enclose many olivine crystals and often show moderately good crystalline outlines (Plate III, figs. 1, 2). Simple twinning occurs infrequently and the dispersion of the axes is evident but not marked. This mineral is in excellent preservation and is often ideally fresh. The felspar (Plate III, fig. 2) is in shapeless masses that fill the interspaces between the other minerals. It often shows incipient decomposition but is for the most part fresh enough to give the usual polarization colours. Albite and pericline twinning are universally present. Often apparently detached areas of felspar extinguish simultaneously over a considerable extent of the slide in such a way as to prove crystalline continuity; hence both the felspar and the augite have micropoikilitic structure. The optical characters of the felspar indicate that it belongs to the labradorite-bytownite series. In convergent light it shows a weakly positive axis with optic axial angle about 82 degrees, indicating about 65 per cent of anorthite. It is never zonal, and when it decomposes it seems to be replaced by prehnite, chlorite and a nearly isotropic, grey substance that is perhaps 'saussurite.' Dark brown biotite and iron ores are scanty and usually cling together.

The *picroteschenite* that forms the lower part of the sill is rather sharply separated from the picrite above, as specimens taken at 189 and 195 ft. are quite distinct. It consists of olivine (abundant, decomposed), augite (reddish-brown, fresh), hornblende (dark brown surrounding augite), biotite, iron ores and felspar (Plate III, fig. 4). Analcite is fairly plentiful, mostly filling interstitial spaces. The felspar is zonal plagioclase usually neither analcitized nor albitized. An analysis of one of these rocks (28003, from 207 ft. deep in the sill) is given on p. 150.

A specimen taken 1 ft. from the base of the sill is teschenite, poor in analcite but rich in carbonates, and carries less olivine than augite.

Specific Gravity

The specific gravities of 39 specimens from the Stankards sill were taken for me in the Survey's laboratory by Mr. E. G. Radley and the results are shown on Fig. 1 in graphic form. As was observed in the case of the Saline, Blackness and Dalmeny[1] sills,

[1] Flett, J. S., 'The Teschenite of Easter Dalmeny,' 'Summary of Progress' for 1929, Pt. iii (*Mem. Geol. Surv.*), 1930, p. 59; 'The Saline No. 1 Teschenite,' *op. cit.* for 1930, Pt. ii, 1931, p. 44; 'The Blackness Teschenite,' *op. cit.* for 1930, Pt. iii, 1931, p. 39.

the original specific gravities of the rock specimens are masked to a considerable extent by the effects of decomposition, which, especially where olivine is altered to serpentine, lowers the specific gravity in proportion to the abundance of the mineral.

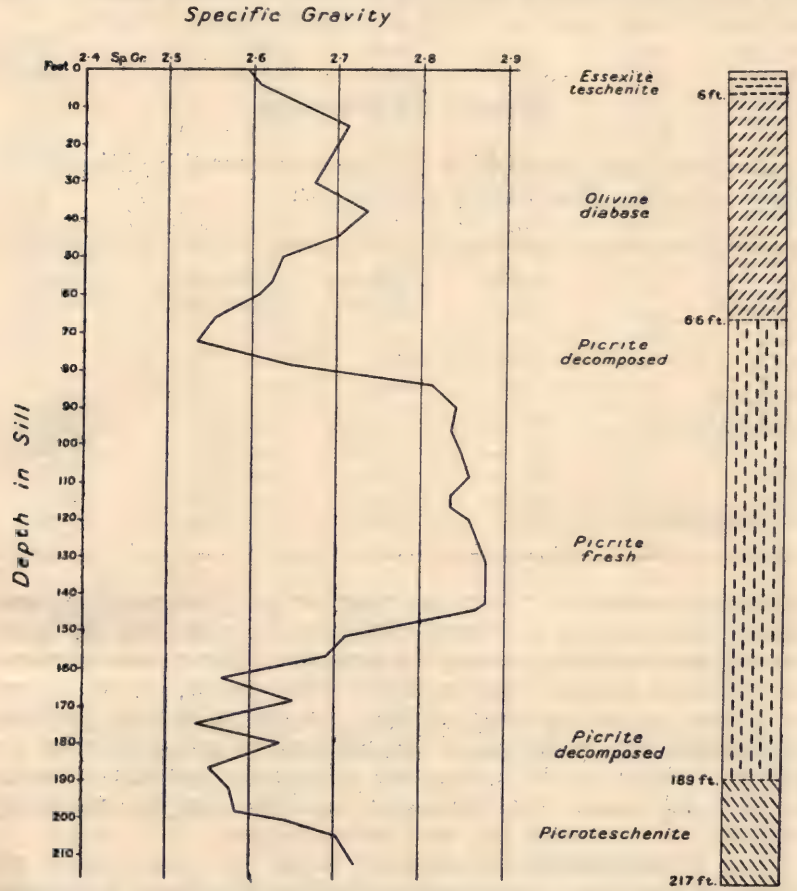


FIG. 1.—*Stankards sill : composition and specific gravity in relation to depth.*

It is evident, however, that the olivine diabase varies comparatively little, having a specific gravity from 2·6 to 2·74. The rotten picrite from 60 to 70 ft. has a low specific gravity while the comparatively fresh picrite ranges mostly from 2·8 to 2·9. At a depth of 150 ft. the picrite again is much decomposed and its specific gravity sinks to 2·53 while the picroteschenite is only slightly less dense than the olivine diabase, from which it differs mainly in containing a little analcite.

In the case of this sill again, as in the Dalmeny and Blackness sills, the main mass of heavy rock is placed below the middle of the intrusion. While there are 66 ft. of olivine diabase above the

picrite there are only 18 ft. of picroteschenite below it. The picrite itself, apart from decomposition, shows no significant variations in gravity. The microscopic sections prove that the transition from picrite to picroteschenite at the base of the picrite mass is more rapid than the passage from picrite to olivine diabase above. The junctions in both cases are fairly well defined but not sharp.

Mineral Composition

I have had the composition of 6 slides measured by Miss E. M. Guppy with the Shand stage micrometer.

Rock	Depth in sill	Olivine per cent	Augite per cent	Slide Number
Teschenite	3 feet	1	16.8	27967
Olivine diabase ...	18 ,,	10.3	13.8	27971
do. ...	36 ,,	13.0	21.9	27974
Picrite	90 ,,	50.4	19.4	27983
do.	135 ,,	54.5	7.1	27991
Picroteschenite ...	207 ,,	23.1	16.9	28003

In the teschenite it was not possible to distinguish between chlorite after augite and serpentine after olivine, but the latter mineral was certainly scanty in amount. These measurements show well the great increase in olivine in the picrite, but the figures for olivine are not absolutely reliable, as when alteration has been considerable the margins of the serpentine pseudomorphs are seldom definite as the serpentine apparently spreads outwards through the rock. On the other hand the augite was easily measured as its crystals had well defined edges.

The picroteschenite is evidently richer in olivine than the olivine diabase, and this is corroborated by the greater percentage of magnesia shown by the chemical analyses. The micrometric measurements also seem to prove that the picrite is not distinctly enriched in augite; in fact some specimens of picrite contain less augite than the other rocks of the sill. On the hypothesis of crystal precipitation this might be explained by the late crystallization of augite, which is indicated also by the generally ophitic structure of the olivine diabase. Much of the augite seems to have formed after the early felspar.

Chemical Composition

Unfortunately the specimens of essexite and teschenite collected were too small to serve for complete chemical analyses.

TABLE I.—ESSEXITES AND TESCHENITES

	A	B	C	D	E
SiO_2	48.63	46.06	43.55	45.71	45.26
Al_2O_3	15.03	15.94	14.84	15.23	15.28
Fe_2O_3	0.51	2.94	3.09	2.84	4.53
FeO	9.55	7.44	7.44	6.93	8.12
MgO	6.34	4.14	7.41	8.11	5.15
CaO	5.95	7.04	7.66	7.34	9.57
Na_2O	5.32	4.95	3.82	3.96	2.98
K_2O	0.56	2.76	1.90	1.31	1.18
H_2O 105° ...	0.93	0.55	1.79	1.54	1.28
$H_2O+105°$ ...	3.16	4.22	5.08	4.70	
TiO_2	2.04	2.56	2.48	1.64	3.46
P_2O_5	0.34	0.84	0.63	0.47	0.59
MnO	0.20	0.31	0.23	0.54	0.40
CO_2	1.12	0.11	0.53	—	2.90
FeS_2	0.44	0.36	0.13	—	—
Cr_2O_3	—	—	—	0.02	—
V_2O_3	—	—	—	0.03	—
(CoNi)O	n.f.	n.f.	n.f.	0.02	tr.
SrO	n.d.	n.f.	n.f.	? tr.	0.02
BaO	0.04	0.10	0.07	0.04	0.06
Li_2O	tr.	? tr.	tr.	tr.	—
S	—	—	—	0.08	0.002
Cl	—	tr.	n.f.	? tr.	—
Totals ...	100.16	100.32	100.65	100.51	100.782

A. Essexite, Lochend, near Edinburgh (*Anal.* E. G. Radley), ' The Geology of the Neighbourhood of Edinburgh ' (*Mem. Geol. Surv.*), 1910, p. 293.

B. Teschenite, Mons Hill, near Dalmeny (*Anal.* E. G. Radley), *op. cit.*, p. 299.

C. Teschenite, Mochrie's Crag, Linlithgowshire (*Anal.* E. G. Radley), *op. cit.*, p. 299.

D. Teschenite, Leckstone Quarry, Blackburn, Linlithgowshire (*Anal.* W Pollard), *op. cit.*, p. 299.

E. Teschenite, Salisbury Crags, Old Quarry (*Anal.* J. B. Harrison and K. D. Reid), H. S. Washington, ' Chemical Analyses of Igneous Rocks,' 1917, p. 888.

TABLE II.—PICROTESCHENITES, OLIVINE DIABASES

	A	B	C	D	E	F
SiO_2 ...	43.82	44.73	43.52	44.62	47.66	46.37
Al_2O_3 ...	10.60	11.89	13.95	10.80	14.03	16.87
Fe_2O_3 ...	4.36	4.85	5.01	5.00	3.13	3.01
FeO ...	6.88	6.61	6.70	8.36	6.04	7.86
MgO ...	12.77	10.77	10.84	15.51	9.65	6.66
CaO ...	6.75	7.69	8.74	6.29	7.74	10.68
Na_2O ...	3.14	2.77	2.72	1.50	2.93	2.44
K_2O ...	1.52	0.89	1.29	0.23	0.84	0.74
H_2O 105° ...	2.66	3.49	2.20	5.50	2.81	3.12
$H_2O+105°$...	4.59	4.15	2.62		3.06	
TiO_2 ...	2.34	1.53	1.69	1.64	1.62	1.63
P_2O_5 ...	0.48	0.46	0.40	0.29	0.27	0.27
MnO ...	0.17	0.41	0.22	0.20	0.16	—
CO_2 ...	0.00?	—	0.05	0.04	0.00?	0.29
FeS_2 ...	0.22	—	0.39	—	0.10	—
Cr_2O_3 ...	0.11	0.05	—	0.07	0.12	0.01
V_2O_3 ...	—	0.03	—	0.01	—	—
(CoNi)O ...	—	0.03	—	0.01	—	0.01
SrO ...	—	tr.	—	0.03	—	0.03
BaO ...	—	0.03	—	0.13	—	0.06
S	—	0.05	—	0.002	—	tr.
Cl	—	n.f.	—	—	—	0.02
Totals...	100.41	100.43	100.34	100.232	100.16	100.07

A. Picroteschenite, Stankards No. 2 boring at 207 ft. depth in sill (*Anal.* B. E. Dixon).

B. Picroteschenite (' picrite '), Blackburn, Linlithgowshire (*Anal.* W. Pollard) ' The Geology of the Neighbourhood of Edinburgh ' (*Mem. Geol. Surv.*), 1910, p. 300.

C. Picroteschenite (' teschenite '), Carcraig (*Anal.* T. C. Day), *Trans. Edin. Geol. Soc.*, vol. xii, pt. ii, 1930, p. 241.

D. Picroteschenite (' picrite '), Colinswell, near Burntisland, Fife (*Anal.* J. B. Harrison and K. D. Reid), H. S. Washington, ' Chemical Analyses, of Igneous Rocks,' 1917, p. 650.

E. Olivine diabase, Stankards No. 2 boring, 42 ft. from top of sill (*Anal.*, B. E. Dixon).

F. Olivine diabase, Barnton Quarry, Corstorphine Hill, Edinburgh. (*Anal.* J. B. Harrison and K. D. Reid), H. S. Washington, ' Chemical Analyses of Igneous Rocks,' 1917, p. 648.

For comparison, however, I have taken the analysis of an essexite and of four teschenites from the neighbourhood of Edinburgh, all belonging presumably to the Lower Carboniferous series of intrusions (Table I). Mr. B. E. Dixon has made an analysis of the picroteschenite of the Stankards boring at a depth of 207 ft. in the sill (Table IIA), and with this are printed analyses of three similar rocks of the same geological series from the Lothians and Fife. Analysis E of Table II has been made by Mr. Dixon from the olivine diabase of the Stankards boring 42 ft. from the top

TABLE III.—PICRITES

	A	B
SiO_2	40.84	39.21
Al_2O_3	6.58	9.56
Fe_2O_3	2.59	5.00
FeO	11.61	9.53
MgO	23.72	23.13
CaO	4.46	5.07
Na_2O	0.91	0.64
K_2O	0.32	0.49
H_2O 105° ...	1.22	1.00
$H_2O+105°$ ...	6.15	4.59
TiO_2	1.29	0.91
P_2O_5	0.21	0.31
MnO	0.21	0.19
CO_2	tr.	0.15
FeS_2	0.06	0.32
Cr_2O_3	0.10	
Totals ...	100.27	100.10

A. Picrite, Stankards No. 2 boring, 90 feet from top of sill (*Anal.* B. E. Dixon).

B. Picrite, Inchcolm (*Anal.* T. C. Day), *Trans. Edin. Geol. Soc.*, vol. xii, pt. ii, 1930, p. 236.

of the sill. In Table III are printed the analyses of the Stankards picrite at 90 ft. deep in the sill, and of the Inchcolm picrite.

These analyses show very clearly the variation in the principal components of the rocks that occur in this intrusive mass. The differences are greatest in magnesia and the alkalies; in lime and silica they are much less striking. This is in agreement with the hypothesis that olivine has been precipitated and that the alkali-silicates have been concentrated in the residual liquor and perhaps also have migrated through pneumatolysis.

Further consideration shows that the sill is by no means symmetrical in the vertical distribution of its types, for apart from

the essexite and teschenite of the uppermost layers, which have no counterpart at the base, the picroteschenite is in many ways different from the diabase as it contains distinctly more magnesia, less alumina and more alkalies. Hence the abundance of olivine and the presence of analcite in the picroteschenite.

Attention may also be directed to the distribution of titanium and phosphorus in the sill. The percentages of titanium dioxide and of phosphoric oxide are notably lower in the picrite than in all the other types. This is an extraordinary fact. It seems to mean that ilmenite and apatite were not precipitated along with olivine though their density is greater than that of the magma and most petrologists believe that they are early minerals. It can hardly be supposed that their crystals floated upwards, and we are led to infer that for some reason they remained in solution in greater quantity in the teschenitic and picroteschenitic parts of the magma (a case apparently of differentiation in the liquid condition).

If we ignore for the present the essexite and the teschenite, which are not present in great bulk and of which we have no analyses from the Stankards sill, it may be of interest to consider whether the Stankards picrite could be obtained by the addition of olivine to either the picroteschenite or the diabase. According to the micrometric measurements the increase of olivine has been about 35 per cent. Taking the composition of olivine from Vesuvius at SiO_2 40, MgO 50, FeO 10 per cent and adding 40 parts of this to 100 parts of (1) picroteschenite and (2) olivine diabase we obtain the following results:

TABLE IV

	A	B	C
SiO_2	42.73	45.47	40.84
Al_2O_3	7.57	10.00	6.58
Fe_2O_3	3.11	2.23	2.59
FeO	7.77	7.17	11.61
MgO	23.40	21.18	23.72
CaO	4.80	5.53	4.46
Na_2O	2.25	2.09	0.91
K_2O	1.07	0.60	0.32
Ti_2O	1.68	1.16	1.29
P_2O_5	0.34	0.19	0.21

A Picroteschenite, Stankards, with 40% olivine added.

B Olivine diabase, Stankards, with 40% olivine added.

C Picrite, Stankards.

These results show on the whole a fair agreement in most respects but there are a few notable discrepancies. The ferrous oxide and the total iron oxides in the picrite are too high but this might be due to a high ferrous content in the added olivine, which at the same time would tend to reduce the excess of magnesia. The differences in the alkalies, however, are much too serious to be disregarded. They show that some other process must have been at work besides the addition of olivine (or olivine and augite). These have been apparently an abstraction of alkalies and probably also of alumina and silica from the picrite, or conversely an addition of these substances to the diabase and picroteschenite.

We cannot assign this difference entirely to the precipitation of early crystals of olivine (and augite). It seems to imply that the uncrystallized liquid into which they sank was different in composition from the picroteschenite and diabase. It cannot be explained by crystallization differentiation even on the extremely improbable hypothesis that alkali-silicates or alkali-alumina-silicates crystallized early and floated upwards in the magma. This evidence seems to indicate differentiation in the liquid condition; the sill appears to have contained layers of fluid magma of different composition. The discrepancy would be still more striking if we took into account the teschenite and essexite layers.

Pneumatolysis

One of the undoubted causes of the richness in alkalies shown by the picroteschenite and the olivine diabase is the albitization and analcitization of their felspars. This is due to a post-consolidation process of pneumatolytic or hydrothermal nature, but it is clear from the microscopic characters of the picrite that the felspars of that rock did not contain originally a notable proportion of alkali felspar that might have been dissolved out and redeposited in the picroteschenite and diabase. The felspars of the picrite are not zonal, and are sometimes remarkably fresh. The alkali silicates must consequently have been in solution in the magma and must have been released as crystallization proceeded. It is equally evident that the essexite, teschenite and picroteschenite contained a fair quantity of original alkali felspar (apart from the enrichment by pneumatolysis).

Protoclastic Structure

In examining the microscopic sections of the picrites, search has constantly been made for evidence that olivine crystals of early formation had sunk in the magma and aggregated to form the picritic facies of the rock. Evidence of that nature would be

provided, for example, by the occurrence of crystals of exceptional size and good crystalline form that had grown very slowly in a supersaturated solution as they gradually sank in the magma. Such crystals also if formed at considerable depths might contain branching fluid cavities. As the magma ascended, these olivines might have been broken up by attrition, especially if we consider that the picrite magma may have contained as much as one-third of its mass of olivine crystals at the time when it was injected into its present position. These early crystals might also be expected to form nodular masses resembling the ' olivine bombs ' of many Tertiary basalts, which would occur as ' autogenous inclusions ' in the picrite or diabase.

The general absence of such evidence is certainly remarkable, but it is interesting to note that in the Stankards sill, for the first time in my experience, some phenomena of this nature have been observed. In two microscopic sections of the picrite taken at depths of 147 feet and 153 feet from the top of the sill, rather below the centre of the picrite mass, there are dense clusters of small well-rounded granules of olivine that appear to be the broken and crushed remains of large olivine crystals or olivine bombs. The rounded grains are very small, less than a tenth of a millimetre in diameter, while the other olivine crystals in the same slides may measure a millimetre across. They are perfectly rounded, as may be seen in the photograph (Plate III, fig. 3) and show no trace of crystalline faces. These clustered grains tend to occur in streaks or bands parallel to what was probably the direction of flow in the magma. They are often included in augite, felspar and biotite crystals, which show the usual characters of those minerals, with occasional crystal faces or irregular outlines, and have clearly not suffered from the process that produced the rounded olivine grains. It is clear that these olivines have been broken, rounded by attrition, and arranged in streaks or schlieren, at a very early period in the history of the rock before the other components had begun to crystallize, and there seems every reason to believe that they are broken-down olivine nodules that belong to a period before the sill was injected. Although I have examined a large number of sections of Scottish picrites I have not previously observed such structures. That they should be so rarely seen is perhaps even more significant than their occasional presence. If thirty or forty per cent of the Stankards picrite had consisted of crystals of olivine at the time of intrusion, phenomena of that kind might have been expected to occur frequently.

Conclusions

In the Stankards sill essexite, teschenite, olivine diabase, picrite and picroteschenite occur together as facies of one intrusion.

The distribution of these types cannot be explained by precipitation of olivine (and augite) after the sill was injected. In some manner the differentiation must have been accomplished either previous to or during intrusion.

There is some evidence of the sinking of early olivine crystals, and this may have been one of the main factors in the development of the picrite.

Other evidence indicates that the liquid part of the magma was not homogeneous throughout, but had undergone differentiation that cannot be ascribed to crystallization and precipitation.

At a late stage in the history of the rock, and probably before complete cooling, there was hydrothermal or pneumatolytic permeation by alkali silicates that gave rise to albitization and analcitization of the primary felspars.

Explanation of Plate III

Photomicrographs of Rocks from Stankards Boring

Fig. 1. Picrite, depth in sill 90 feet, magnified 12 diameters, ordinary light. Slide No. 27983.

Many small crystals of olivine weathering to serpentine. At left above and right below large crystals of augite, partly idiomorphic, enclosing olivine crystals.

Fig. 2. Picrite, depth in sill 111 feet, magnified 32 diameters, ordinary light. Slide No. 27987.

Many crystals of olivine, partly fresh, enclosed in augite in right and in felspar in left part of field.

Fig. 3. Picrite, depth in sill 147 feet, magnified 25 diameters, ordinary light. Slide No. 27993.

Many small crystals of olivine, rounded and broken up by attrition, occupy the left side of the field.

Fig. 4. Picroteschenite, depth in sill 207 feet, magnified 12 diameters, ordinary light. Slide No. 28003.

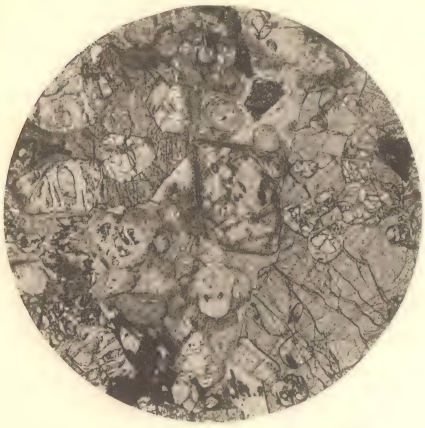
The dark grains are mostly olivine, weathered to serpentine. The augite is grey, the felspar nearly white. At the right lower margin there is a patch of interstitial ' primary ' analcite enveloping felspar, augite and biotite.

Fig. 5. Olivine diabase, depth in sill 30 feet, magnified 35 diameters, crossed nicols. Slide No. 27973.

Large crystal of albitized plagioclase, simply twinned, showing the speckled effect.

Fig. 6. Olivine diabase, depth in sill 30 feet, magnified 35 diameters, crossed nicols. Slide No. 27973.

Plagioclase partly albitized and showing speckled effect. Islands of original plagioclase, dark in the photograph, are surrounded by speckled albite but are not themselves speckled.



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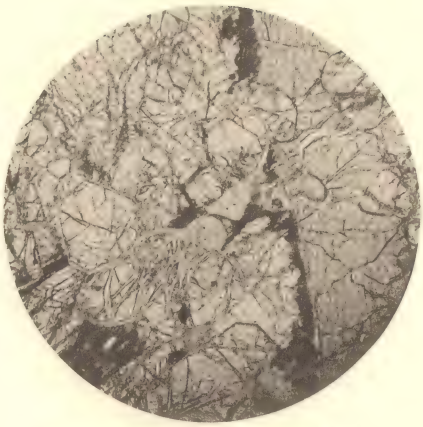

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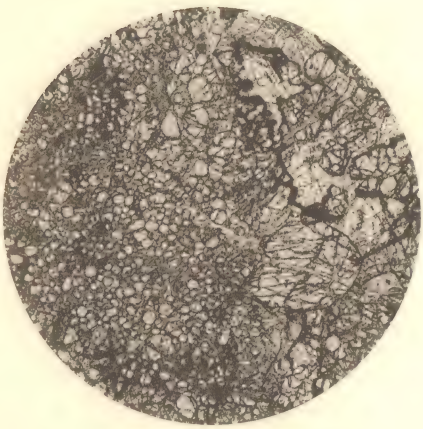

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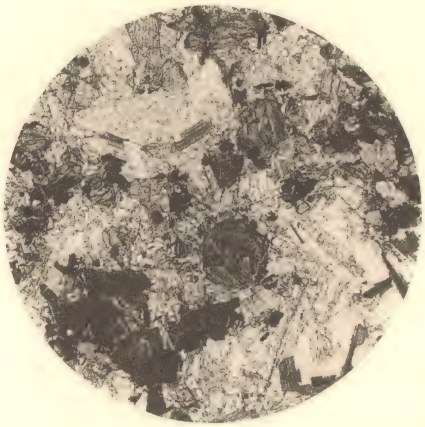

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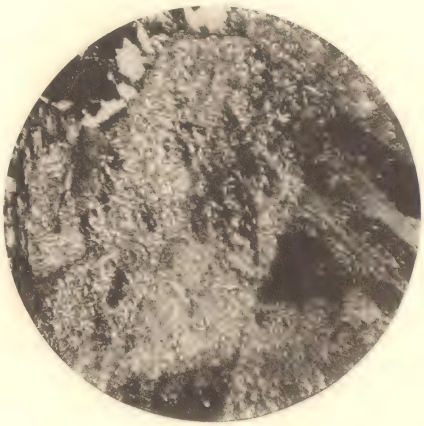
5 ×35



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ROCKS FROM STANKARDS BORING.

XI.—ON THREE NEW SPECIES OF FISH FROM THE OLD RED SANDSTONE OF ORKNEY AND SHETLAND

BY

PROFESSOR D. M. S. WATSON, F.R.S.

Plate IV; Text-figures 1-5.

IN his classic paper on the Old Red Sandstone of the Orkneys,[1] Sir John Flett says on p. 386, '*Coccosteus decipiens* (Ag.) [occurs] . . . even in the [Eday] sandstones at Deerness, as I learned from Mr. Magnus Spence of Deerness, who forwarded a specimen he found in Newark Bay to Dr. Traquair. To these we must add a new and undescribed species of Asterolepis, of which scattered plates were found by Mr. Spence of Deerness and myself in Deerness, Holm, and South Ronaldshay. . . . This interesting fossil is, so far as we know at present, confined to a narrow belt of the flagstones immediately underlying the Eday sandstones, where it occurs with *Dipterus valencienesii* (Sedgwick and Murchison), and *Glyptolepis paucidens* (Ag.); and should further investigations confirm this restricted distribution, it may eventually be taken to mark the existence of a palaeontological sub-zone immediately beneath that of *Tristichopterus alatus* (Egert.).' The great collections made during the past three years by the collectors of the Survey have contained further specimens of the *Coccosteus* from Newark, and of the Deerness *Asterolepis*, which are described below.

The actual specimen from Newark sent by Mr. Spence to Dr. Traquair, who determined it as *Coccosteus decipiens*, remained in the latter's private collection till his death, when it passed into the possession of the British Museum. Mr. Spence subsequently found another *Coccosteus* in Newark Bay, which he gave to the present writer, who in turn presented it to the Manchester Museum, where it is No. L. 11945.

In 1927 the Survey collected from a locality 420 yards E. 8 degrees N. of Inganess Farm, 1½ miles S.E. of Kirkwall, parts of a single skeleton of a very large *Coccosteus*, clearly differing from all previously described.

A direct comparison shows that the two specimens from Newark belong to the same new species, and as the Manchester specimen is by far the most complete, though only a little more than one third the size of the others, I base the following description mainly on it.

[1] Flett, J. S., 'The Old Red Sandstone of the Orkneys,' *Trans. Roy. Soc. Edin.*, vol. xxxix part 2, 1898, pp. 383-424.

Coccosteus fletti sp. nov.

Text-fig. 1.

The specimen has been prepared by removing the bone fragments which remained and now shows the dorsal surface of the head and of the body armour, together with a posterior ventro-lateral and a fragment of an anterior ventro-lateral.

The head-shield is essentially complete, though not well preserved in the pineal-ethmoidal region; the right pre- and post-orbitals have been displaced. The general structure is as in *Coccosteus decipiens* Ag., but the shield has a much more rounded contour, with much less prominent postero-lateral corners and a wider anterior margin. The orbital notch is much smaller and more deeply excavated. The median occipital is narrower than in *C. decipiens,* the lateral occipitals broader and with more nearly parallel borders.

The central plates have much less lateral extension and appear to have met the pineal plate. The lateral line grooves have a normal distribution but are unusual in the very wide separation and divergence of the supra-orbital canals, though the exaggeration of this character may be due to the youth of this specimen.

The body armour differs in detail from that of *C. decipiens,* but is of course built on the same plan.

The dorso-median is short and wide, with a rounded hinder end. The median ridge and process on its visceral surface are well shown in the specimen from Inganess Farm. They differ very remarkably from those of all other Scotch *Coccostei* in their slenderness and small dimensions. The process, which becomes the 'handle' of a *Dinichthys* plate, is actually only half the height which it has in a *C. decipiens,* in which the whole plate has only one half of the width in the new specimen. All the lateral elements of the body armour differ in shape between the two species, the anterior lateral being much more slender at its lower end, and the posterior lateral being short and wide and lacking ornament at its lower end.

The ventral armour is short and broad, all its elements being reduced in length and widened in comparison with *C. decipiens.*

The lateral line grooves on the body are peculiar in that the dorsal lateral line does not, as usual, extend on to the median dorsal to form the familiar V-shaped groove, but runs back, parallel to the median plane on to and across the posterior dorso-lateral. The lower lateral line must run on to the posterior lateral but cannot be seen on the example of that bone which forms part of the Inganess specimen.

The differences between this new species, which may appropriately be called *Coccosteus fletti,* and *C. decipiens,* will be more readily understood from a comparison of text-figures 1 and 2 than from any description.

The only other *Coccostei* which are sufficiently completely known to be comparable are:—

C. minor H. Miller, which is only about $\frac{1}{7}$ as long, has much larger and more deeply incised orbits and a long spine on the dorso-median.

C. canadensis A. S. Woodward, which is of the same size as *C. fletti*, differs in the lack of divergence of the supra-orbital canals. It has much longer and narrower anterior and posterior ventro-laterals, but it seems to resemble *C. fletti* in lacking a spine on the dorso-median, and in the small size of the visceral process from that plate.

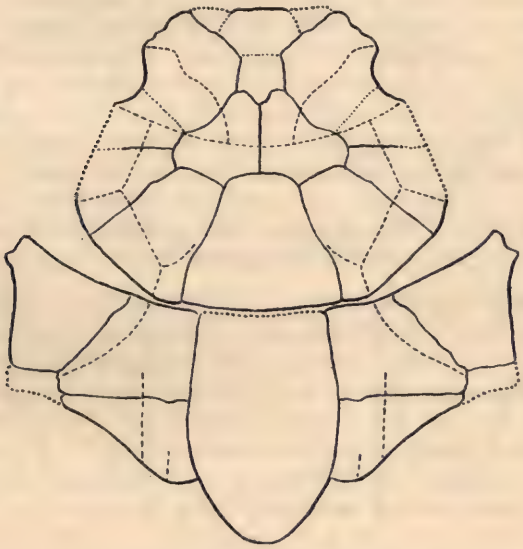

FIG. 1.—*Diagram of the dorsal dermal armour of* Coccosteus fletti *from a specimen,* No. L. 11945, *in the Manchester Museum; from Newark Bay, Orkney.*

C. fossatus Eastman, known only from the anterior part of the head-shield, differs in the nearly parallel course of the supra-orbital canals, but resembles *C. fletti* in that the pineal meets the central plate.

C. occidentalis Newb. differs in that its dorso-median is spined.

C. livonicus Pander differs absolutely in the strong development of the visceral process of the dorso-median.

[*C. magnus* Traq. is too inadequately known to be compared.]

C. disjectus A. S. Woodward clearly differs in the elongated shape of the posterior median ventral plate and in the shape of the posterior ventro-lateral.

The individuals of *Coccosteus fletti* from Inganess Farm and from Newark Bay appear to have been obtained from the same horizon lying at, or indeed below, the base of the Eday Beds. No trace of the animal has been found in any other locality, so

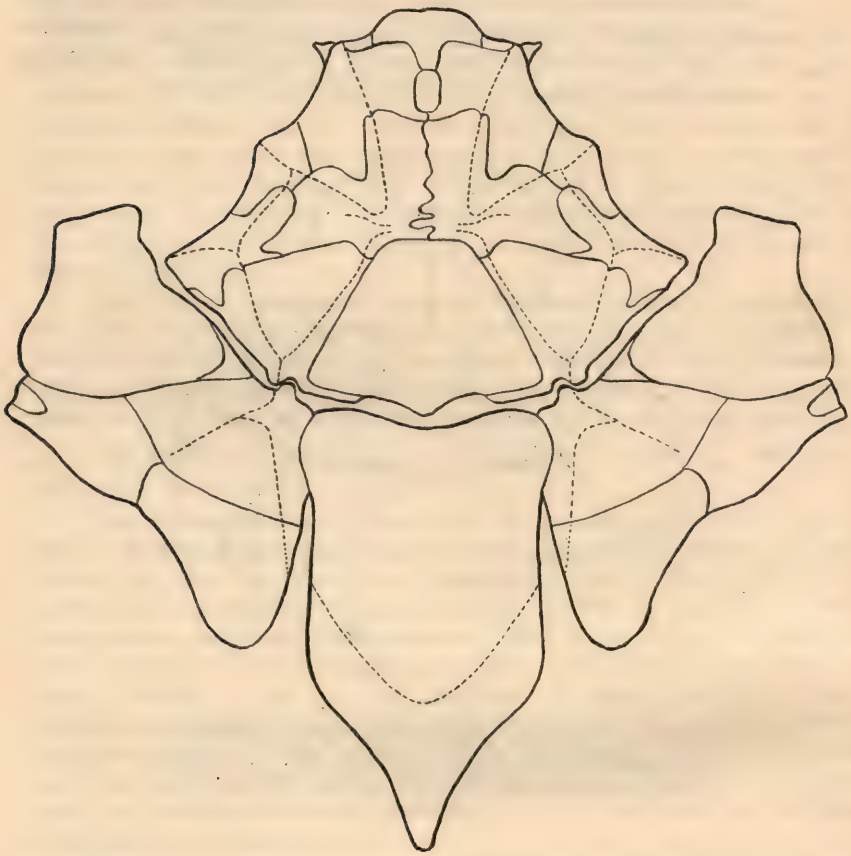

FIG. 2.—*Diagram, for comparison with Fig.* 1, *of* Coccosteus decipiens *Ag. entirely from* No. C. 35, *Geological Department, University College, London. Lethan Bar, Moray Firth.*

that I am inclined to regard it as of limited vertical range, and it may ultimately serve to mark off a definite horizon toward the summit of the Rousay Beds. What stratigraphical relation such a horizon bears to that which has yielded *Asterolepis orcadensis*, I do not know, but I am inclined to believe that the *Coccosteus* lies somewhat higher than the *Asterolepis*.

Asterolepis orcadensis [Traquair MS.] sp. nov.

Plate IV, figs. 1, 2. Text-fig. 3

The specimen, collected by Sir John Flett from flagstones immediately below the Eday Beds, at Long Geo, Holm, Deerness, Orkney, which was determined by Dr. Traquair as a new species of *Asterolepis,* is No. 1898, I. I. in the Royal Scottish Museum. It consists of an entire but much cracked anterior dorso-median, seen from its visceral surface. This specimen gives the entire form of the plate when the detached fragments of its left lateral margin are in a drawing replaced in their original position. It possesses, and clearly shows, the characteristic feature which distinguishes *Asterolepis* itself from all other Asterolepids. In it the entire lateral margins bear rabbets for the anterior and posterior dorso-laterals, so that it overlapped these plates throughout its extent.

Dr. Traquair also determined as *A. orcadensis* a large posterior dorso-lateral from Brough Head (Hest Head), S. Ronaldshay, Orkney. This is incomplete and badly preserved and I have been able to make little use of it.

The new Survey collections contain the following specimens of this new form. They were found by Mr. W. E. Strachan.

V. 1810 B. An impression of the dorsal surface of the head-shield, excellently preserved and showing the whole structure admirably.

V. 1819 B. The anterior part of a right anterior dorso-lateral, preserved as a bone.

V. 1820 B. The posterior end of a right anterior dorso-lateral, chiefly as a mould.

V. 1821 B. Part of a left posterior dorso-lateral.

V. 1810 B came from old quarry, 130 yds. E. 43° S. of Monquhanny Farm-house, Shapinsay, and the others from shore at Coopalash, Burroughston, Shapinsay.

It is clear that all the materials necessary for a dorsal reconstruction of the animal are available, and I have drawn Fig. 3 to illustrate this view. This figure was drawn on the assumption that all the parts except the head belonged to individuals of the same size, the head of the figure having been enlarged about 10 per cent.

The head has the ordinary structure but differs from *Asterolepis maxima* (Agassiz), *A. ornata* Eichwald and *Pterichthys* in that its lateral margins incline towards one another anteriorly, that the ' angular ' plate is exceptionally large, the lateral borders of the median occipital are straight and not indented by the lateral occipitals, and that the lateral border of the lateral is convex. In all these respects the head-shield approaches *Bothriolepis.*

The lateral line grooves on the head fall into two groups, that in which they form wide grooves, and that in which they are fine, only distinguishable by their straightness and continuity from the ornament of the skull.

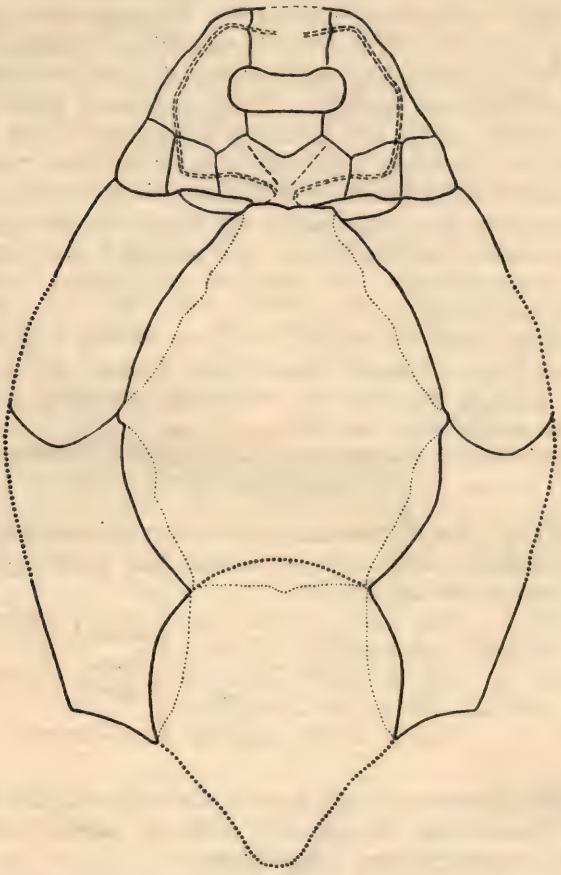

FIG. 3.—*Reconstruction of the dorsal surface of* Asterolepis orcadensis *sp. nov., half natural size of body armour. Head-shield* No. V. 1810 B. *Anterior median dorsal* No. 1898 I. I., *Royal Scottish Museum. Anterior dorso-lateral* Nos. V. 1819 B *and* V. 1820 B. *Posterior dorso-lateral* No. V. 1821 B.

The only representative of the first group is the pair of lines which begin in the median occipital, pass out into the lateral occipital, then suddenly turn forward over the lateral, finally passing mesially on to the premedian, where they probably join one another.

To the other group belong a pair of grooves which lie entirely in the median occipital, beginning near its centre point and diverging round the post-median. These grooves are continued posteriorly by other short grooves which lie in a special short

lappet projecting backward from the middle of the median occipital. The arrangement of the lateral line on the head thus combines the structures normally found in *Asterolepis* with those characteristic of *Bothriolepis*.

The anterior median dorsal plate is seen from its inner surface; it has been crushed flat, and its thin overlapping margins have been broken into fragments, which on the left side remain nearly in position. It shows quite clearly and definitely the characteristic feature of *Asterolepis*, that the median dorsal overlaps both the anterior and posterior dorso-lateral plates, and is itself overlapped by the posterior median dorsal.

The excavation of the visceral surface of the anterior end, which overlapped the head-shield, is unusually clearly shown.

The whole bone is exceptionally wide, bears a low median ridge, and was apparently considerably vaulted.

The anterior dorso-lateral is well shown by its anterior end in V. 1819 B, and posterior end in V. 1820 B. It does not differ in any way recognizable, in the incomplete materials which are available, from that of *Asterolepis maxima*.

The best posterior dorso-lateral is V. 1821 B, which lacks its anterior end and lower margin. It is a characteristic plate of *Asterolepis*, differing from that of *A. maxima* in its greater depth and long free posterior border.

It is obvious from the character of the isolated plates, that the body armour of *A. orcadensis* was very short and wide when compared with that of *A. maxima* and *A. ornata*; it was perhaps also somewhat deeper in proportion to its length, though not relatively to its width.

Asterolepis orcadensis differs entirely from all other known forms in its width and in the wedge-shaped outline of its head-shield. As I have pointed out, it presents certain resemblances to *Bothriolepis*, slight but unmistakeable, but is none the less, in the mode of articulation of its body-plating, typically an *Asterolepis*. Its age is quite certain; it comes from beds very near the upper limit of the Thurso or Rousay Series, and is hence, in all probability, the oldest known member of the genus. Its distribution in several localities in Orkney suggests that it marks a definite horizon, and the few fish which are associated with it, chiefly remains of a small *Dipterus* commonly regarded as *D. valenciennesi*, are consonant with this view, because these specimens of *Dipterus* are always characterized by a very small size and peculiar appearance which distinguishes them from those of all low horizons. I am not at the moment prepared to point out definite characteristics which will allow of the recognition of a new species for these fishes, but hope and expect ultimately to be able to do so.

Asterolepis thule sp. nov.

Text-figs. 4, 5.

The Survey's collection from Shetland, amongst material obtained from a sloping cliff-base forty yards south of the lighthouse at Sumburgh, Shetland, contains a number of fragments clearly belonging to a single species of *Asterolepis*. The most satisfactory of these, B. 519 1, which has an incomplete counterpart, B. 520, is a head-shield lacking the premedian plate and both sufflaminals (Stensiö's new term for the old angular plate of Traquair). The right lateral is somewhat misplaced but the left is in position. The head-shield retains its original curvature and is considerably arched. In general proportion it agrees fairly closely with the head-shield of *Asterolepis maxima* and of *A. ornata*, particularly with the latter, but it differs in the unusually great length of the post-median plate. One curious feature of the ornament, which is well displayed on the mould, is the presence, immediately lateral to the orbit on the lateral plate, of a triangular area whose surface bears much smaller and lower tubercles than those which occur on the greater part of the head-shield. An exactly similar piece of ornament is to be found in *A. maxima*, whilst in perfectly preserved laterals of *A. ornata* figured by Stensiö, the same condition is only very faintly traceable.

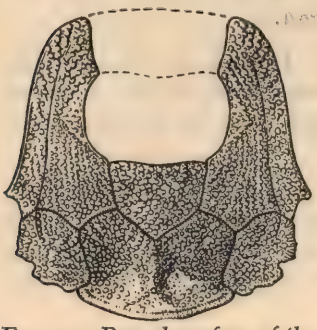

FIG. 4.—*Dorsal surface of the head-shield of* Asterolepis thule *sp. nov., natural size, slightly reconstructed from specimens* B. 519 1, *and* B. 520 1.

The head-shield as a whole is exceedingly long and narrow, in this feature somewhat resembling the conditions found in *Pterichthys*. The same locality has yielded an anterior dorso-median plate, B. 616, which, though not quite complete, is sufficient to make it quite evident that we are dealing with a true *Asterolepis* and not a *Pterichthys*, because it is obvious that this plate overlapped both the anterior and posterior dorso-laterals. The other fragments are of no interest.

None of the described species of *Asterolepis* conform to this type and it clearly represents a new form, for which I propose the name *Asterolepis thule*. It is none the less to all appearances closely allied to the typical *Asterolepis ornata* and *A. maxima*, and it is natural to regard it as an Upper Old Red Sandstone form. But the minute fragments of other fish which are associated

with it, and of which the most important is the anterior part of the dorsal head-shield of an unknown Osteolepid, throw no light on the problem of the age of these beds.

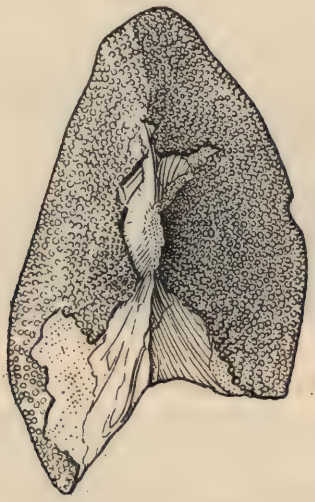

FIG. 5.—*Anterior median dorsal of* Asterolepis thule *sp. nov., natural size. Specimen* No.B.616.

I am greatly indebted to Sir John Flett and the Officers of the Survey for the opportunity of examining the very extensive material from Orkney and Shetland, of which these three species form a part. It is very remarkable that after so long an interval, new Old Red Sandstone fishes should be found in Orkney. The earlier discoveries of Sir John Flett and Mr. Finlay have already shown that Shetland might be expected to provide new things, and indeed the materials I have so far dealt with from that group of islands are most difficult to handle, because whilst extremely fragmentary they clearly represent in the main, entirely new forms not represented farther south.

Explanation of Plate IV

Fig. 1. Photograph of the dorsal surface of the head-shield of *Asterolepis orcadensis* [Traquair MS.] sp. nov., natural size. Geol. Surv. Coll., V. 1810 B. The sutures and lateral line grooves have been outlined with white paint.

Fig. 2. Anterior dorso-median of *Asterolepis orcadensis*, natural size. Royal Scottish Museum, specimen No. 1898, 1. 1. The bone, the fragments detached from its margin, and the inner limits of the rabbets by which it overlapped the anterior and posterior dorsal plates, are outlined in white.

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